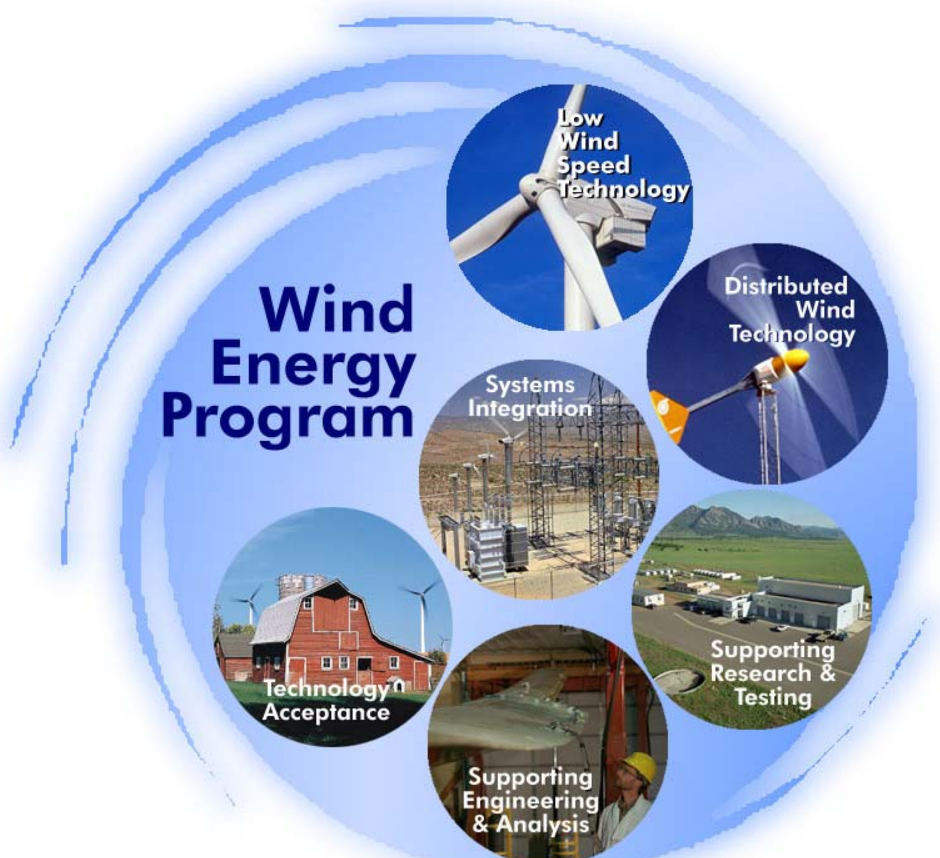
Harnessing America's abundant natural resources for clean power generation

Wind and Hydropower Technologies Program

Wind Energy Program Multi Year Technical Plan

For 2004-2010



U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable.

November 2003

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1.0 Introduction

The Wind Energy Program ("Wind Program"), managed by Office of Energy Efficiency and Renewable Energy of the United States Department of Energy, is a broad-based effort focused on increasing the viability of wind technology for use in the emerging energy marketplace. The Wind Program is one element of the Office of Wind and Hydropower Technologies Program.

1.1 Scope

This Multi Year Technical Plan describes the Wind Program's support for research on wind turbines for utility and distributed applications. The Plan includes activities that target both technology development and institutional barrier reduction. Because wind systems can meet a wide range of needs in the marketplace, the Wind Program is sponsoring activities that target the needs of the wind research community, manufacturers, wind plant developers, and the energy-consuming public.

This Plan describes program research activities and milestones for a seven year time horizon (2004-2010). In developing the Plan, the Wind Program assumes that funding levels will remain at about the FY 2003 levels until the latter part of the planning horizon, when activities will begin to taper off as goals for elements of the program are met and research activities conclude.

1.2 Background

The Federal government has been sponsoring wind systems research since 1972. The early program, at the National Science Foundation, was driven by the needs of electric utilities and by the potential of wind as a "fuel saver" during the oil crisis. This utility focus led to a program to develop large-scale wind turbines. Other elements of the early program included technical and market analysis, environmental impact assessment, innovative systems design, vertical axis wind turbine development, and farming applications. The program also provided design review and testing for small turbine manufacturers.

At that time, analysts believed that large turbines had a strong potential for economies of scale; energy production would be increased by tapping the better resources accessible using taller towers; and that utilities would primarily be interested in larger-sized units. When the program began, the feasibility of using large wind turbines (defined as turbines rated at 100 kW or larger) for grid-tied generation had not been established. The Mod-0, installed in 1975, and its variant, the Mod-0A, a 100-kW turbine that was operated at four sites, proved the feasibility of large turbine technology and provided a test bed for further innovation. The first megawatt-scale wind turbine, the Mod-1 (1979-1980), generated annoying noise, leading to research into noise mitigation. Three Mod-2 turbines, rated at 2.5 MW each, were deployed from 1980-1986. These turbines demonstrated several design innovations, but also experienced loads and stresses that were far above those originally anticipated. The 3.2-MW Mod-5B, the largest and last turbine in the series, corrected the significant design shortcomings of the Mod-2 machines and passed its acceptance tests, but never achieved commercial acceptance, in part because of the unfavorable market conditions created by low oil prices. While these large turbine designs were never deployed commercially, this research identified the limitations of early design approaches and helped define the scope of subsequent research and development efforts.

Other notable program work in the late 1970s and early 1980s included: the development of a National Wind Atlas that is still in use today, in updated form; initiation of airfoil research that reduced sensitivity to fouling, which was a problem with blade designs using aircraft airfoils; and work on improved materials and structural designs that has developed into an extensive knowledge base used by today's designers. That early work also began to define the somewhat unexpected complexity of the wind inflow, and to identify ways to mitigate its negative effects on turbine reliability and lifetime.

As a result of favorable development incentives and regulatory reforms, California became a hotbed of wind power development between 1981 and 1985. (Figure 1 provides a chronology of developments in the post-1980 era.) The turbines used in these installations were all much smaller than the systems developed by the earlier Large Turbine program. Industry developed these small systems to reduce risk in the absence of modeling and design tools. The incremental steps followed by the small turbine manufacturers allowed extrapolation of lessons learned to machines of increasing size and sophistication,

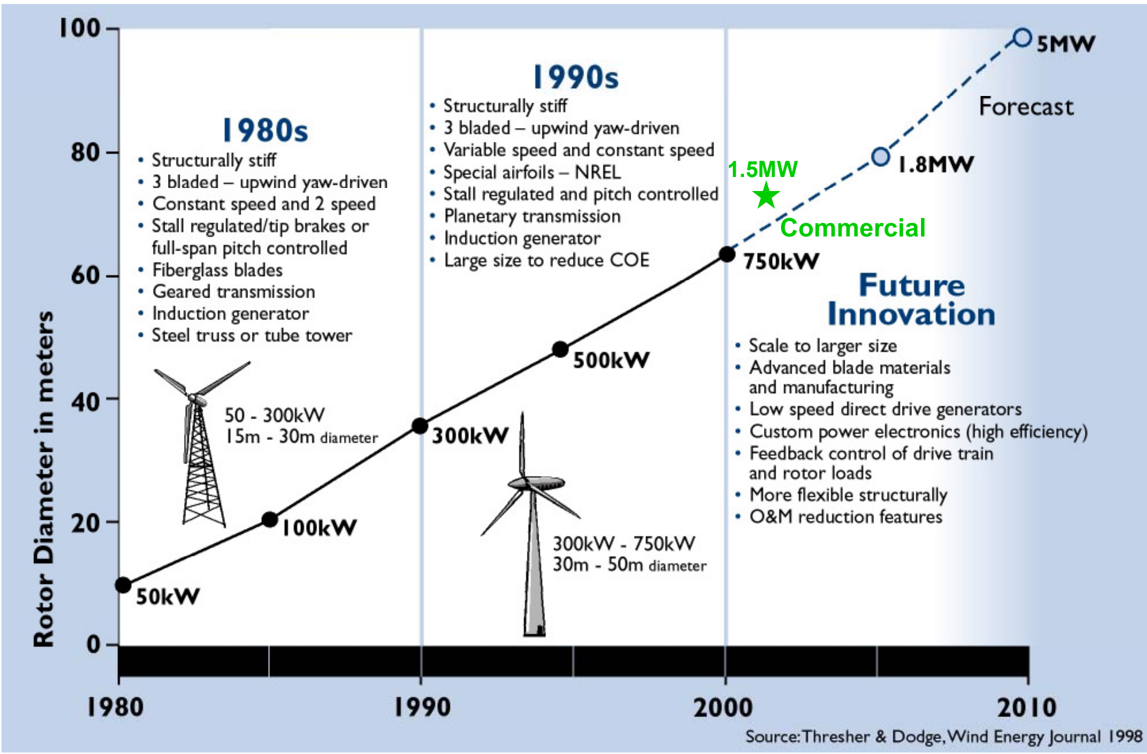


Figure 1. Wind Technology Developments Beginning in 1980

while taking advantage of available policy support. The initial California turbines came from U.S. companies, but within a year or two, very sturdily designed Danish, Dutch, and other European turbines captured increasing market share. When new installations began dropping off in 1986, due to a decline in tax credits and California market incentives, many of the U.S. manufacturers went bankrupt.

In 1990, the program refocused its activities and developed a new strategy that focused on collaborative activities with utilities and industry. This new emphasis arose from the experience gained from earlier R&D activities, and from guidance of the National Energy Strategy (NES), which was developed in 1989 and 1990. An important element of that strategy was to help broaden wind's use beyond California. To that end, four objectives were adopted: 1) maintain present generation; 2) increase industry competitiveness; 3) upgrade the research base; and 4) develop advanced wind turbines.

The industry-driven strategy that was implemented in the early 1990s laid the groundwork for today's R&D program. It began a series of program-sponsored efforts to work closely with industry to develop wind turbines that are significantly more cost-competitive than their predecessors. The Advanced Turbine Program, which led to cost-effective designs in the better wind regimes, and the WindPACT studies of new components and subsystems both followed from this new strategy.

The remainder of this Plan details the focus and strategy of the Wind Program as it builds upon the important R&D successes of the 1990s.

1.3 Authority

The Wind Program operates under the following statutory authorizations:

- P.L. 94-163, Energy Policy and Conservation Act (EPCA) (1975)
- P.L. 94-385, Energy Conservation and Product Act (ECPA) (1976)
- P.L. 95-91, Department of Energy Organization Act (1977)
- P.L. 95-619, National Energy Conservation Policy Act (NECPA) (1978)
- P.L. 101-218, Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989
- P.L. 101-575, Solar, Wind, Waste and Geothermal Power Production Act of 1990
- P.L. 102-486, Energy Policy Act of 1992 (EPACT)

In addition, low wind speed technology development is recognized in the National Energy Policy (NEP) as an opportunity for significantly expanding wind energy use.

2.0 Program Benefits

2.1 Vision of Wind Future

Wind energy will become a major source of energy for the nation, which has only begun to tap its vast wind resources. The wind community has set a target of 100 GW of wind electric capacity installed in the U.S. by 2020. At that level of utilization, wind will be displacing about 3 quadrillion Btus of primary energy per year, and 65 million metric tons of carbon equivalent per year. Extensive deployment of smaller wind systems, in distributed settings, is also part of industry's target. The Wind Program embraces that vision of the future potential for wind.

Beyond that vision, the Wind Program also believes that wind energy can become an important element of the future energy economy in which hydrogen becomes a key energy carrier. When that happens, wind will provide clean, inexpensive energy for the nation's transportation needs. As described in this plan, the program has already begun efforts to expand the resource base to include lower wind speed areas, both on land and offshore. Innovative technologies and reduced constraints to wind's use, as fostered by program efforts, will help this future vision become a reality.

2.2 Goals and Objectives

2.2.1 National Needs

The United States faces many challenges as it prepares to meet its energy needs in the twenty-first century. Electricity supply crises in California, fluctuating natural gas and gasoline prices, heightened concerns about the security of the domestic energy infrastructure and of foreign sources of supply, and uncertainties about the benefits of restructuring are all elements of the energy policy challenge.

2.2.2 DOE Goals

The Department of Energy Strategic Plan (draft August 6, 2003) describes four strategic goals in support of achieving the Department's mission. These goals are in the areas of defense, energy, science, and the environment. The Energy Strategic Goal is the most relevant to the Wind Program. All of the Wind Program's efforts support that goal, as shown in Figure 2.

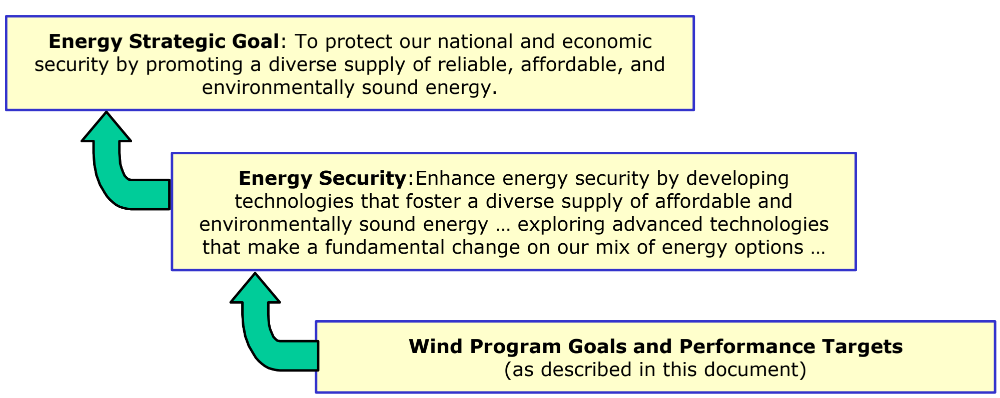


Figure 2. Relationship of Wind Program Goals to DOE Strategic Goals

2.2.3 Office of Energy Efficiency and Renewable Energy Goals

The Office of Energy Efficiency and Renewable Energy (EERE) leads the Federal government's research, development, and deployment efforts in energy efficiency and renewable energy. EERE's Strategic Plan, published in October 2002, describes nine strategic goals. These include reducing dependence on foreign oil, reducing the burden of energy prices on the disadvantaged, increasing the efficiency of buildings and appliances, reducing the energy intensity of industry, and creating a domestic renewable energy industry. Most relevant to the Wind Program is the priority to:

> *Increase the viability and deployment of renewable energy technologies, by improving performance and reducing costs, and by facilitating market adoption of renewable technologies*.

2.3 Wind Program Mission and Goals

Responding to these national energy policy priorities, the Wind Program has recently begun charting new directions for its efforts. These directions are being organized around the two thrusts described by the Assistant Secretary for Energy Efficiency and Renewable Energy. They are:

- *Increasing the viability of wind energy* - developing new cost-effective technology for deployment in less-energetic, Class 4 wind regimes; developing cost-effective distributed, small-scale wind technology; and performing research that supports these technology viability activities.
- *Increasing the deployment of wind energy* - helping facilitate the installation of wind systems by providing supporting research in power systems integration, technology acceptance, systems engineering, communication and analytical support.

The wind program research portfolio includes both near-term and long-term focused research to provide a balance between the need to work with industry to solve pressing short-term technical issues and the need to maintain U.S. industry momentum as a technological innovator. Balancing this portfolio and assuring that a variety of approaches exist to achieve the goals are the challenges of the program planning function.

2.3.1 Program Mission

The Wind Program's mission is to "*support the President's National Energy Policy and Departmental priorities for increasing the viability and deployment of renewable energy; lead the Nation's efforts to improve wind energy technology through public/private partnerships that enhance domestic economic benefit from wind power development; and coordinate with stakeholders on activities that address barriers to use of wind energy."*

2.3.2 Program Goals

The program has defined goals for its technology viability and technology application activities that will position wind as an attractive advanced technology option for the twenty-first century. These goals are:

- By 2012, reduce the cost of electricity from large wind systems in Class 4 winds to 3 cents/kWh for onshore systems or 5 cents/kWh for offshore systems.
- By 2007, reduce the cost of electricity from distributed wind systems to 10-15 cents/kWh in 2007 in class 3 wind resources, the same level that is currently achievable in class 5 winds

- By 2012, complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs.
- By 2010, facilitate the installation of at least 100 MW in 16 states.

2.4 Strategic Planning

Figure 3 provides an overview of the program's strategic planning framework, which has two elements. First, the program has an on-going Technical Assessment activity – to monitor the current status of wind technology and progress in achieving program cost goals, to evaluate that status within the context of the needs of the marketplace, and to identify technological pathways that will lead to wind's successful competition in the marketplace. The program also uses a formal Peer Review process – to benefit from

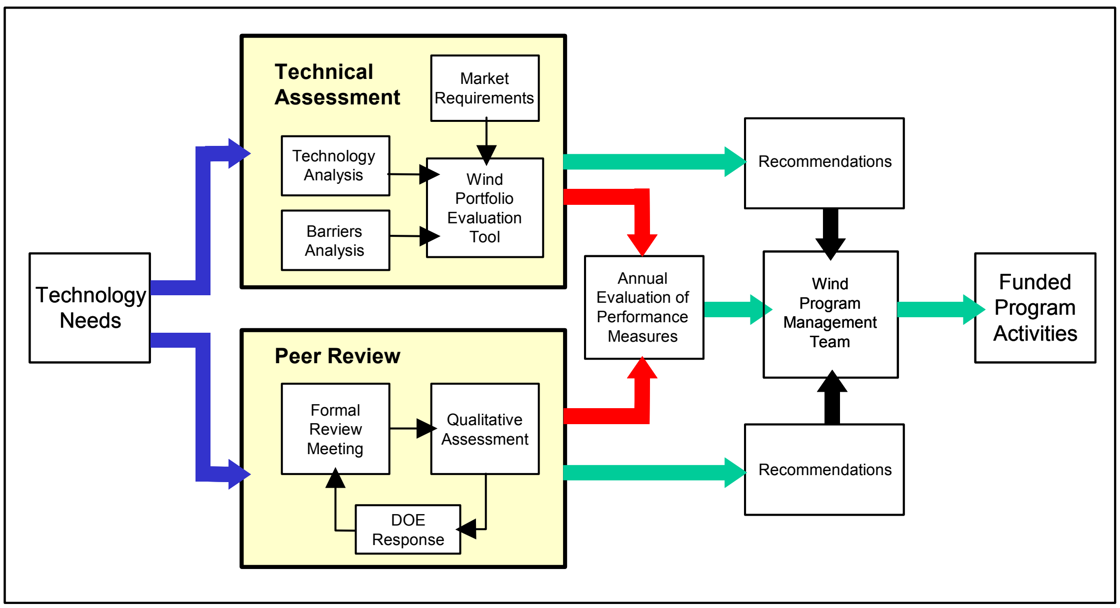


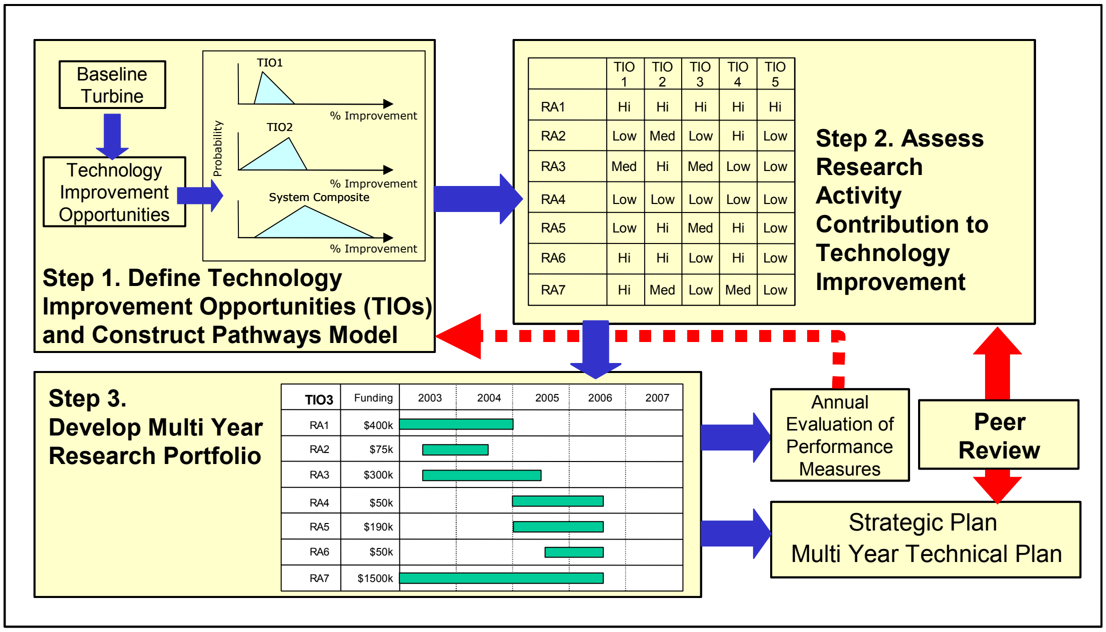
Figure 3. Strategic Planning Framework

the guidance of industry and the research community, and to provide an outside view of the program. As shown in Figure 3, Technical Assessment and Peer Review provide inputs that the Program Management Team considers in making decisions about strategic program directions and funding priorities. The Technical Assessment and Peer Review activities are described in the following sections.

2.4.1 Technical Assessment

The technical assessment process ensures that every research activity supported by the program can be demonstrated to have a direct link to achieving the top-level objectives and goals of the Wind Program, the Office of Energy Efficiency and Renewable Energy, and DOE. The technical assessment process is outlined in Figure 4 and described in more detail in Appendix A.

The technical assessment effort is built around a Technology Pathways structure. In developing the focus on Class 4 resources, program researchers, technical consultants, and peer reviewers have defined a 2003 Baseline Turbine configuration, against which R&D progress will be measured. This 2003 Baseline Turbine is the beginning point for the Pathways analysis and the reference point for the technical assessment activity. The Technology Pathways analysis structure is used for the assessment of all program support for technology development, as will be described in Chapter 4.



	TIO 1	TIO 2	TIO 3	TIO 4	TIO 5
RA1	Hi	Hi	Hi	Hi	Hi
RA2	Low	Med	Low	Hi	Low
RA3	Med	Hi	Med	Low	Low
RA4	Low	Low	Low	Low	Low
RA5	Low	Hi	Med	Hi	Low
RA6	Hi	Hi	Low	Hi	Low
RA7	Hi	Med	Low	Med	Low

TIO3	Funding	2003	2004	2005	2006	2007
RA1	$400k					
RA2	$75k					
RA3	$300k					
RA4	$50k					
RA5	$190k					
RA6	$50k					
RA7	$1500k					

Figure 4. Technical Assessment Process

The technical assessment process can be described as including three steps:

1. Characterization of Technology Improvement Opportunities – In this step, the program identifies areas of possible cost reduction or performance enhancement to the baseline configuration, or Technology Improvement Opportunities (TIOs). Examples of TIOs include rotor efficiency enhancements, increased reliability, and reduced design margins. These areas are then further assessed, using the Wind Technology Pathways Model, to quantify their potential contribution to improving the technology's cost-effectiveness. Cost of energy is used as a focus for this analysis because it captures the capital investment cost and performance trade-offs facing turbine designers. Appendix A provides a detailed discussion of the Wind Technology Pathways Model.
2. Research Activity Prioritization and Performance Goals – In this step, program planners identify the research activities necessary to achieve the TIOs. Each research activity's potential contribution to technology improvement is identified. Research activities that contribute little to achieving technical targets (such as RA4 in the example figure) are terminated. Those contributing the most are given the highest funding and management priority.
3. Detailed Portfolio Planning – Finally, after developing a prioritized list of research activities, program planners then formulate the program's research plan over the planning horizon.

An important element of the Technical Assessment process is to perform annual assessments of progress toward program goals, and to incorporate peer review feedback into program prioritization activities. The analyses conducted under this Technical Assessment activity are also used in program estimates of annual benefits under the Government Performance and Results Act (GPRA).

2.4.2 Peer Review

In May of each year, the Wind Program holds its formal peer review. The peer review process provides a means for the program to receive formal feedback on its efforts. Peer reviews are conducted in a manner that conforms to Departmental guidance for the conduct of peer reviews. The results of the review are considered when the management team evaluates potential adjustments to program direction. A senior program advisor, who has strong technical credentials but is not directly affiliated with the program or any of the programs' contractors, manages the peer review process. This Peer Review Director works with program personnel to select the peer review team, which typically has five to ten members.

The Peer Review Meeting is an intensive three to four day technical event with topical sessions structured around major program research efforts. The presentations are open to all invitees (including staff from headquarters, the labs, contractors, etc.). Speakers make formal presentations on their research programs and then are subjected to questions. The Peer Review Panel is facilitated in its deliberations, and presents its findings in the Peer Review Report. During the summer, peer review efforts are incorporated into the portfolio evaluation effort. In the fall, the program reconvenes the peer review team to reach an understanding about program priorities and direction.

2.4.3 Performance Measurement and Strategic Assessment

The program uses a formal performance measurement and technology tracking process to guide multi-year planning and to realize the benefits of performance-based management. The Wind Technology Pathways approach, described in Section 2.4.1 and Appendix A, is also used for this progress measurement process. As described in Chapter 3, the program has identified four goals that encompass all of the program's activities. Tracking annual progress toward meeting these goals is an important element of the program's performance measurement strategy. Specific details about how each of these four is defined, and how they will be tracked, are found in Sections 4.1.2, 4.2.2, 4.3.2, 5.1.2, and 5.2.2.

2.4.4 Program Planning and Implementation Documents

The combined efforts of the Technical Assessment and the Peer Review result in four key program documents:

- Strategic Plan – a broad statement of the program's goals, objectives, and priorities.
- Multi Year Technical Plan – a detailed description of program activities and schedules, milestones, and performance metrics for each Research Activity. Like the Strategic Plan, the Multi Year Technical Plan is a forward-looking document. Both documents require assumptions to be made about future funding levels.
- Program Execution Plan – a specific plan for the current operating year. The PEP is different from the Strategic Plan and the Multi Year Technical Plan in that it reflects the actual funding levels of the current year and the current status of research efforts.
- Annual Wind Turbine Technology Update – an annual report on progress made from the 2003 baseline toward program technology performance goals.

3.0 Technical Plan Overview

The Wind Program focuses on the dual elements, or Key Activities, of its mission – to increase the technical viability of wind systems and to increase their deployment in the emerging marketplace. Figure 5 shows that there are six subkey activities in these two elements.

For Technology Viability, the program is pursuing low wind speed technology, distributed wind technology and supporting research and testing to achieve continued progress in the two technology development areas. To increase Technology Application, the program sponsors research on systems integration, technology acceptance, and systems engineering and analysis. (Note – A fourth Technology Application subkey activity, Resource Assessment, will end in FY04, and some elements were transferred to other subkey activities.) Figure 5 lists the Research Goal for each subkey activity and provides a brief summary of primary research efforts in each area.

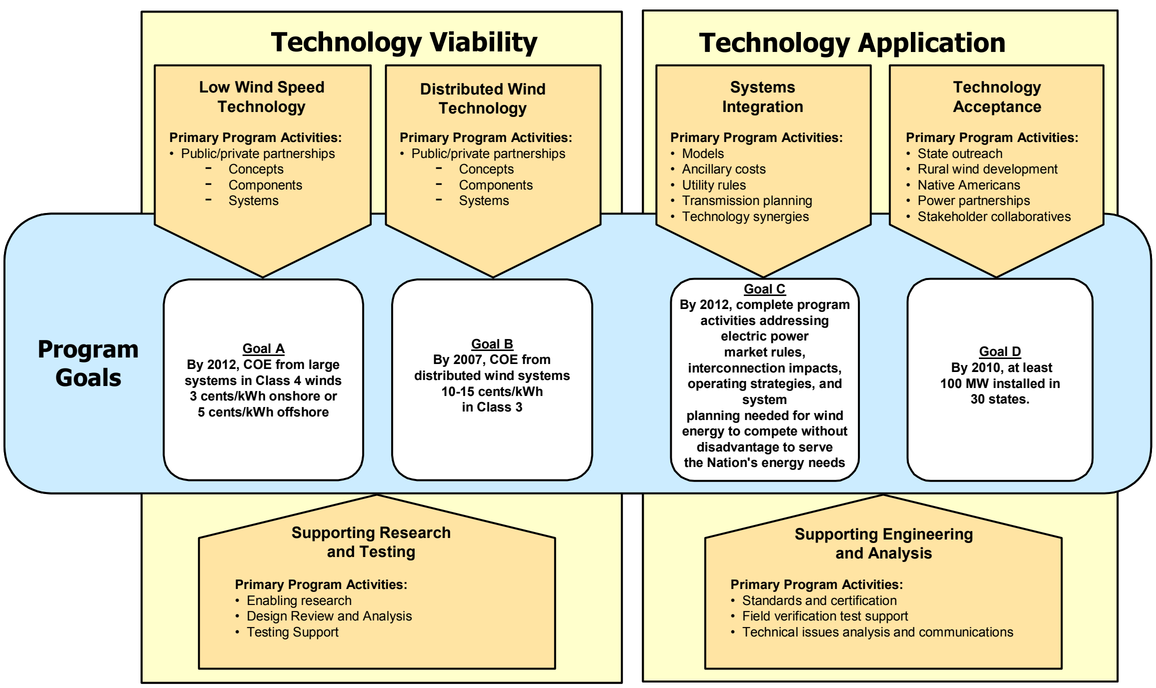


Figure 5. Wind Program Structure (FY2005-2010)

Table 1 provides a key activity-level summary of the funding profile assumed for this plan. Details are provided in Sections 4.0 and 5.0. The profile shown assumes a relatively constant total funding level. Because final funding decisions are made by the Department of Energy on a year-by-year basis, this projection will be revisited annually.

Table 1. Multi Year Funding Profile for Wind Program (millions $)

Subkey Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Technology Viability	29.8	31.0	31.8	31.1	32.1	32.1	31.8
Technology Application	11.8	9.8	9.8	10.5	9.5	9.5	9.0
Total	41.6	40.8	41.6	41.6	41.6	41.6	40.8

4.0 Technology Viability

The Technology Viability research efforts focus on helping industry to develop technology that will improve the cost-effectiveness of large and small wind energy systems. For program management purposes, and to assure appropriate high-level management focus on these activities, the Technology Viability key activity is managed as three separate subkey activities: 1) Low Wind Speed Technology (LWST); 2) Distributed Wind Technology (DWT); and 3) Supporting Research and Testing (SR&T).

The three Technology Viability subkey activities are closely interrelated. Figure 6 shows the interrelationship between the LWST subkey activity and the SR&T subkey activity. A similar relationship with SR&T exists for the DWT subkey activity.

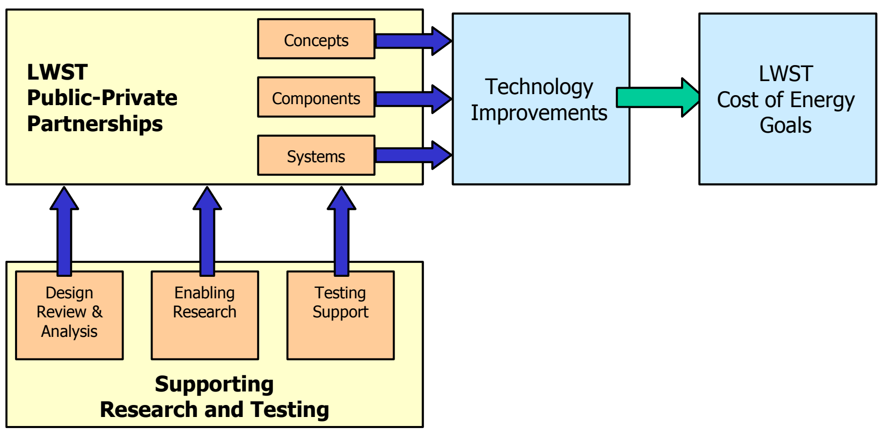


Figure 6. Relationship of SR&T and LWST activities to program goals

As Figure 6 shows, success in reaching the LWST cost goal will result primarily from the efforts of industry through the public-private partnerships sponsored by DOE. While industry partners will have the primary responsibility for those efforts, program research staff will play an important enabling role. This supporting role can take several forms, and, depending on the specific project, might include project oversight, supporting analysis, testing support, or other enabling technical support that brings specializ4ed expertise, which the industry partners might not have in-house, to bear.

Reductions in the COE from current levels to the goal level will not occur as a result of one single change in turbine configuration, or particular technology breakthrough. Those reductions will come from the combined contributions of many different, smaller advances. As will be described in more detail later, industry partners have identified a variety of technology and hardware approaches that could contribute to this lowering of the COE, and have proposed to pursue these changes in their partnerships with DOE. The program refers to these as Technology Improvement Opportunities (TIOs). As the program tracks progress toward the COE goal, it also tracks progress against each of the TIOs. Appendix A provides a more detailed description of how TIO progress and COE progress are inter-related and tracked.

The program tracks and reports annual progress in COE reduction through a process program researchers have named the “Annual Turbine Technology Update.” In this Multi Year Technical Plan, COE reductions, and the Annual Turbine Technology Update, are used as the performance measure for LWST activities (Section 4.1.2). Progress against specific TIOs is used as the SR&T measure (Section 4.3.2). However, the two are clearly very closely related and such distinction is somewhat arbitrary.

The remainder of this chapter describes the program's plan for Technology Viability activities. Table 2 provides a detail of the annual funding assumptions for subkey activities under Technology Viability. Because program funding allocation decisions are made annually, these values may be adjusted each year. The figures do not in any way represent a commitment by the program to future funding.

Table 2. Multi Year Funding Profile for Technology Viability (millions $)

Subkey Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Low Wind Speed Technology	12.0	13.2	14.0	14.3	15.3	16.3	16.0
Distributed Wind Technology	2.0	2.0	2.0	2.0	2.0	1.0	1.0
Supporting Research and Testing	15.8	15.8	15.8	15.8	15.8	15.8	15.8
Total	29.8	31.0	31.8	31.1	32.1	32.1	31.8

4.1 Low Wind Speed Technology

The Low Wind Speed Technology (LWST) subkey activity is advancing the development of technology that will allow wind to compete in Class 4 (average wind speeds of 5.8 m/s at 10 m height) wind regimes. The availability of technology that can compete in these wind regimes is important to wind's continued expansion in the U.S. due to the wide-spread availability of Class 4 wind resources, both onshore and offshore.

4.1.1 Goal

The research goal of the Low Wind Speed Technology subkey activity is: "By 2012, reduce the cost of electricity from large wind systems in Class 4 winds to 3 cents/kWh for onshore systems or 5 cents/kWh for offshore systems."

4.1.2 Technical Approach

Strategy

The strategy of the LWST subkey activity is to use public/private partnerships to achieve technical advances in concept designs, component development, and full-scale prototypes. Figure 7 shows the LWST strategy. This work builds upon previous program efforts – the WindPACT advanced technology studies and the Next Generation Turbine program. The LWST partnerships are cost-shared efforts with industry. The completion of each partnership cycle represents an important Wind Program milestone. The strategy of using multiple rounds of solicitations serves three purposes. First, it allows multiple entry points, allowing industry partners to participate as each company's needs dictate. Second, it gives companies the opportunity to receive follow-on funding to pursue concepts or designs identified in earlier rounds. Third, it gives the program an opportunity to end support for a particular idea if it is not producing the expected results. As can be seen in the figure, the Supporting Research and Testing subkey activity provides critical support to the LWST effort, as will be discussed in Section 4.3.

Performance Measures

Levelized cost of energy (COE) will be used to measure progress in the LWST effort. The targeted output of this effort is a commercially available turbine prototype that produces electricity in Class 4 winds for 3 cents/kWh for onshore systems (in constant levelized dollars) or 5 cents/kWh for offshore systems by 2012. Achieving that COE level will be possible through the incremental technology improvement opportunities presented by the various LWST subsystem and prototype efforts and by the SR&T effort.

Determining COE for full scale prototypes will be a relatively straightforward task, based on industry experience with the maturation of technologies and manufacturing processes. Determining the COE impact of improvements in individual components and subsystems will be based on comparisons with a reference, or baseline, design with a well established COE. The impact of technology advances will be assessed, on a yearly basis, throughout the course of the LWST project. Estimates of their COE impact will be based on the progress made under existing subcontracts and development efforts at the time of the assessment, allowing a clear picture of the impact of improvements on the overall goals and objectives. Figure 8 illustrates this performance tracking process, as it might appear at the end of 2008.

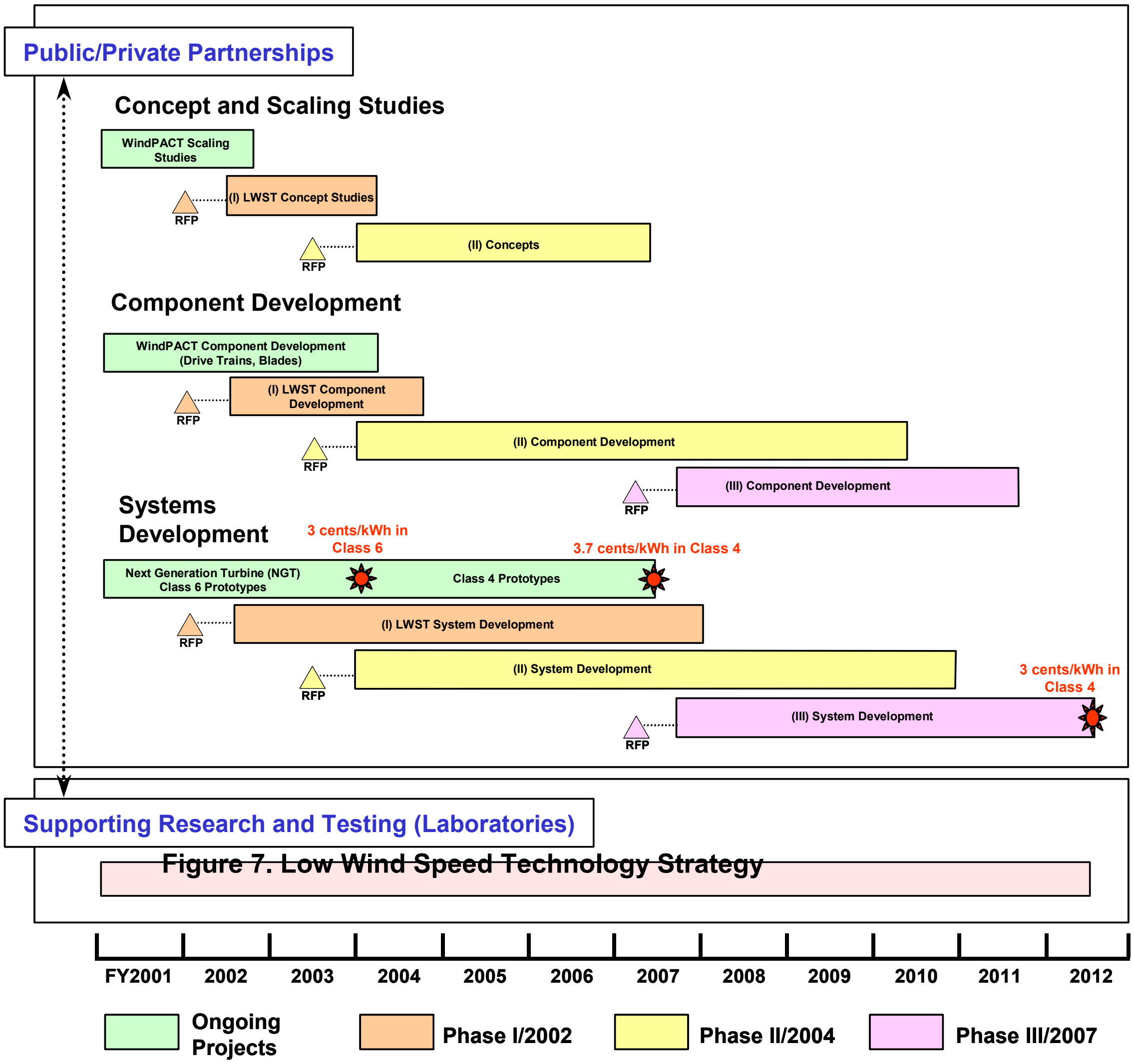


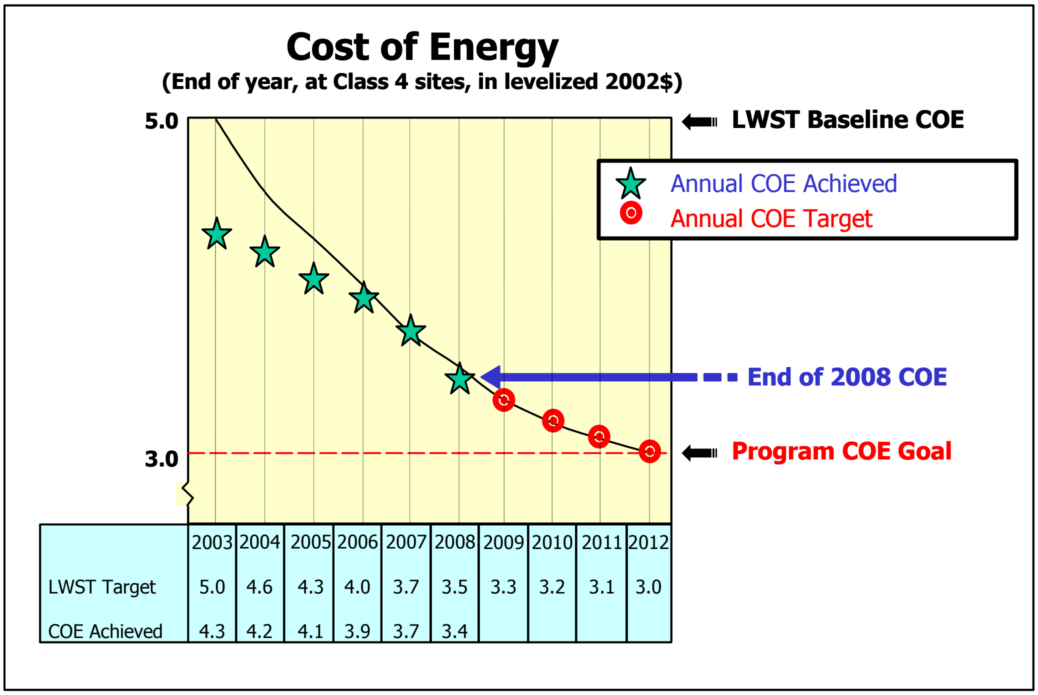
Figure 7. Low Wind Speed Technology Strategy

If this annual assessment determines that a particular research effort is not yielding the expected results, and is unlikely to contribute significantly to COE reductions, the Wind Program will terminate the activity. The program's peer reviewers will be consulted, as described in section 2.4.2, when such determinations are being made.

4.1.3 Technical Challenges

Competitive COE levels for wind have been achieved by focusing development on Class 6 sites and by taking advantage of the federal Production Tax Credit (1.8 cents/kWh in 2003 $). With favorable financial terms, wind farms at Class 6 sites can market electricity at prices of 4 cents/kWh or less, without the subsidy. However, many Class 6 sites are located in remote areas that do not have easy access to transmission lines. In addition, as more and more sites have been developed, prime Class 6 sites that are easily accessible are becoming scarce. The full development of accessible Class 6 sites may cause wind energy growth to plateau in the near future unless improvements in technology can make lower wind speed sites more cost effective.

To this date, wind turbine designers and manufacturers have had little need to look beyond designing for Class 6 sites. This has allowed them to proceed with a steady progression toward larger rotor diameters and incrementally lower costs. By pursuing incremental design changes, they have also been able to lessen design risk. However, studies conducted under the WindPACT project indicate that more complex design improvements will be required to achieve the greater decreases in COE needed to achieve the DOE goals. These design improvements represent opportunities as well as significant challenges.



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
LWST Target	5.0	4.6	4.3	4.0	3.7	3.5	3.3	3.2	3.1	3.0
COE Achieved	4.3	4.2	4.1	3.9	3.7	3.4				

Figure 8. Example of Wind Turbine Technology COE Tracking Process (Example is for the year 2008)

Wind turbines are currently capable of producing electricity at 4.3-5.0 cents/kWh in the Class 4 wind regimes that are broadly available across the United States. Class 4 wind resources in the U.S. are relatively well characterized. However, these turbine designs are not well-suited to low wind regimes and have only limited potential to achieve lower costs of energy. The WindPACT projects, as previously described, have identified a broad range of concepts that have been demonstrated in studies to reduce the overall cost of energy. Given this potential, the challenge now remains of reducing those concepts to practice. Many wind energy companies are using the WindPACT studies as a guide to the selection of advanced technologies for development.

While the technical issues associated with onshore LWST turbine development are relatively well understood and a fairly well defined approach can be identified, the same cannot be said for offshore wind technology. Current design concepts and visions are based upon limited experience with sheltered shallow water sites. Costs associated with offshore technology currently run 1.3 to 1.5 times higher than onshore developments, or 7 to 8 cents/kWh in US dollars. U.S. experience is literally nonexistent though several projects have been proposed and are in the preliminary stages of development. U.S. locations with significant resources do not match previously developed European sites well. Many of the U.S. sites will require the application of technologies that have yet to be explored or seriously considered in Europe, especially those that will allow development in deeper waters, which may have greater wind, wave and ice loading. In addition, numerous environmental, political and regulatory issues exist in the U.S., which must be dealt with in the near term before significant development can get underway.

New design concepts must be more fully developed and tested in rigorous laboratory or field environments before they can add their contribution to the reduction of the total life cycle cost of energy from wind. Based on the previous work, the Wind Program has performed a technology pathways analysis to ensure that appropriate and adequate research efforts are underway to allow the program to meet its LWST cost goal. The analysis was described briefly in section 2.4.1.

4.1.4 Research Activities

In 2001, the Wind Program launched a major new effort to reach the LWST goal. The program currently envisions that the LWST project will represent an increasingly larger portion of total program funds over the remainder of this decade. The strategy for the LWST project was developed in cooperation with industry, and guided by several principles:

- Public/private partnerships will be developed to support continuing innovation. They will be flexible and adaptive, support multiple pathways, and offer repeated opportunities for new players to enter the program.
- Both onshore and offshore technology will be eligible for funding.
- Program research and testing activities will be closely aligned to support public/private partnerships.
- Applied systems integration activities will guide portfolio planning and technology transfer.
- Program evaluations using performance-based management techniques will provide a strong analytical basis for performance criteria, periodic review, and adjustment.

The LWST project will have three phases of open solicitations for the development of advanced technology (Figure 7). In general, each of the three phases will allow industry participation in three types of projects. The first type is for conceptual design studies. Design studies offer an industry partner an opportunity to determine the probable value of a particular concept by performing a paper analysis before undertaking detailed design and fabrication. These small scale studies (approximately $200,000) are non-cost-shared and the results are in the public domain. These studies are intended to lead a developer to the next round of solicitations, where they may choose to more fully develop their idea. The second type of project is a cost-shared component development project. In this type of project, the industry partner completes detailed design and testing of an advanced prototype component or subsystem. Such components are expected to reduce the cost of an existing design, or to serve as the basis for an entirely new prototype design. The third type of project calls for the cost-shared detailed design, fabrication and testing of an advanced prototype turbine. These turbines will be tested in field environments that demonstrate the likelihood of achieving the LWST goal.

Each subsequent phase of solicitations offers an opportunity for a team that has developed a concept or component to complete their development cycle by developing a complete turbine prototype. This three-phased approach with three different types of projects allows the program to develop a broad portfolio of technologies and partners. Such a broadening of the technology base provides a higher likelihood that the goals and objectives will be met in the projected time frame. Conversely, all partnership efforts are established with clearly defined tasks and deliverables. Task reviews are established at key points throughout each project to allow termination or redirection of projects that are not achieving their goals.

Activity Status – By early 2003, seven subcontracts were underway as part of the Phase I of the LWST solicitations. These efforts include two drive train (gearbox and generators) developments, one power electronics/power conditioning project, one advanced blade development, and one full scale advanced prototype. As of early 2003 three additional subcontracts were being negotiated (one for an advanced telescoping tower, one for an advanced blade, and one for a full scale prototype development). Each of these subcontracts focuses on a technical area previously identified as having a high potential impact on COE reduction at low wind speed sites.

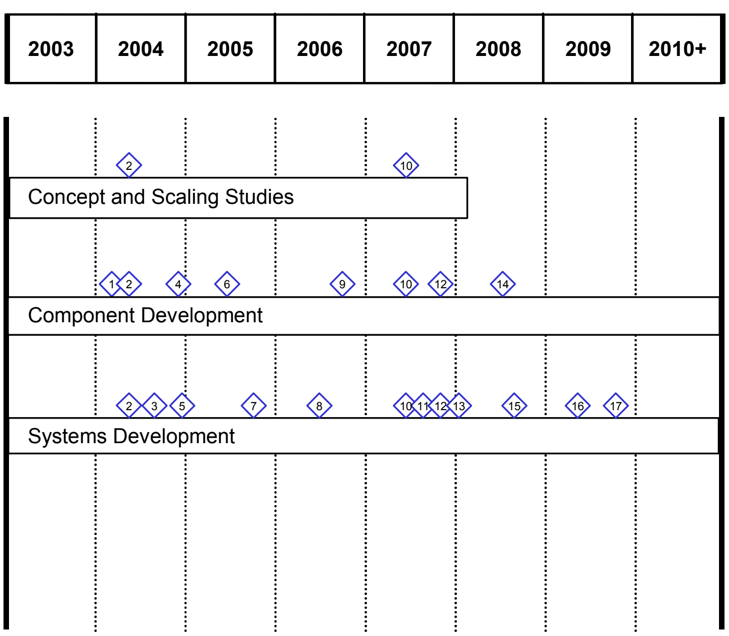
Technical Plan – Under the continuation of this effort, the project will issue two additional solicitations. One solicitation is planned for late in 2003. Prototype turbines developed from this solicitation are expected to be operational in 2007. A third solicitation is expected for 2006, with prototypes available for testing in 2010. Each of these solicitations is expected to engage major industry partners in exploring the issues associated with developing low wind speed technology. Concept studies are expected to lead to Component and Full Prototype Developments. The DOE program will use the WindPACT studies in helping to evaluate the likelihood that proposed projects will contribute to COE reduction. Because no set of studies can be all-inclusive, the program will evaluate new concepts as they are identified to determine their likelihood of contributing to COE reduction. All proposals provided by industry are required to estimate the COE reduction from any proposed technology, using a standard method. This approach facilitates the comparison of competing technologies, to assist in selecting those that offer the greatest return on DOE's R&D investment.

The program anticipates that future industry-proposed LWST efforts will include advanced drive trains with novel configurations; advanced power electronics to improve overall efficiency and provide higher-quality power; lighter and quieter rotors made with new materials; advanced controls to monitor overall system health and reduce maintenance costs; and new, taller tower designs that can be assembled cost-effectively on-site.

4.1.5 Milestones

Milestones for the Low Wind Speed Technology subkey activity provide planning guidance and a means by which progress can be tracked.

Low Wind Speed Technology



Milestones

1. Begin testing of advanced blade.
2. Select public-private partnership participants for second round of development.
3. Complete detailed design of first public-private partnership project for full system development.
4. Complete testing of two advanced drive-train prototypes.
5. Begin testing first full scale prototype turbine.
6. Begin testing of advanced variable speed power converter.
7. Complete detailed design of second public-private partnership project for full system development.
8. First turbine commercially available.
9. Begin testing of advanced components from second round of development.
10. Initiate third round of projects.
11. Begin testing of first shallow water offshore prototype.
12. Select public-private partnership participants for third round of development.
13. Begin testing of second round full scale prototype turbine for onshore deployment.
14. Begin testing of advanced components from third round of.
15. Begin field verification testing of early commercial.
16. Begin testing of third round full scale prototype turbine for onshore deployment that achieves 3 cents/kWh in class 4.
17. Begin testing of first offshore deep water prototype.

4.2 Distributed Wind Technology

The Distributed Wind Technology (DWT) subkey activity is working with the small wind turbine industry to develop advanced technology to make distributed wind technology cost-effective in much wider regions of the country, and for a wide variety of applications. Similar to the LWST, the DWT subkey activity is focusing on technological innovation that can lessen the requirement for average wind speed, moving the design focus from Class 5 to Class 3.

4.2.1 Goal

The research goal of the Distributed Wind Technology subkey activity is: "By 2007, reduce the cost of electricity from distributed wind systems to 10-15 cents/kWh in Class 3 wind resources, the same level that is currently achievable in Class 5 winds."

4.2.2 Technical Approach

Strategy

The strategy of the DWT effort is to use public/private partnerships to help industry develop a cost-effective low wind speed small turbine that meets distributed energy needs. These partnerships may also develop cost-effective components such as inverters, rotors, and tall towers, and develop conceptual designs to guide future technology innovation. Figure 9 shows this strategy. As is the case for LWST research, the Supporting Research and Testing subkey activity provides important support to this effort. The DWT partnerships also allow multiple entry points and offer industry the chance to receive follow-on funding to pursue opportunities identified in previous rounds.

Performance Measures

The Wind Program has identified cost of energy (COE) as the primary indicator of progress in distributed wind technology development. Specifically, the Wind Program is seeking to reduce the COE from small wind systems to the point where they have the same cost effectiveness (10-15 cents/kWh) in Class 3 wind resources in 2007 as they currently have in Class 5 resources (Figure 10). The upper end of the COE goal range is for grid-connected residential-sized turbines, while the lower end of the range is for small commercial-sized turbines. The program will also track cost in terms of other measures such as $/annual kWh of electricity production and $/kW of installed capacity.

Cost of energy is particularly appropriate for prototype development activities, since it embodies the full systems perspective required to create a commercially viable product. However, the program will develop performance goals for each development activity that it sponsors, recognizing that, in the smaller size range, there will be a wider variety of cost and performance specifications, depending on application, required levels of reliability, etc.

4.2.3 Technical Challenges

In 2001, annual sales of the U.S. small wind turbine industry were estimated to be 13,400 turbines, valued at about $20 million. The U.S. small wind turbine industry offers a wide assortment of products for various applications and environments. Machines range in size from those that generate 400 watts (W) of

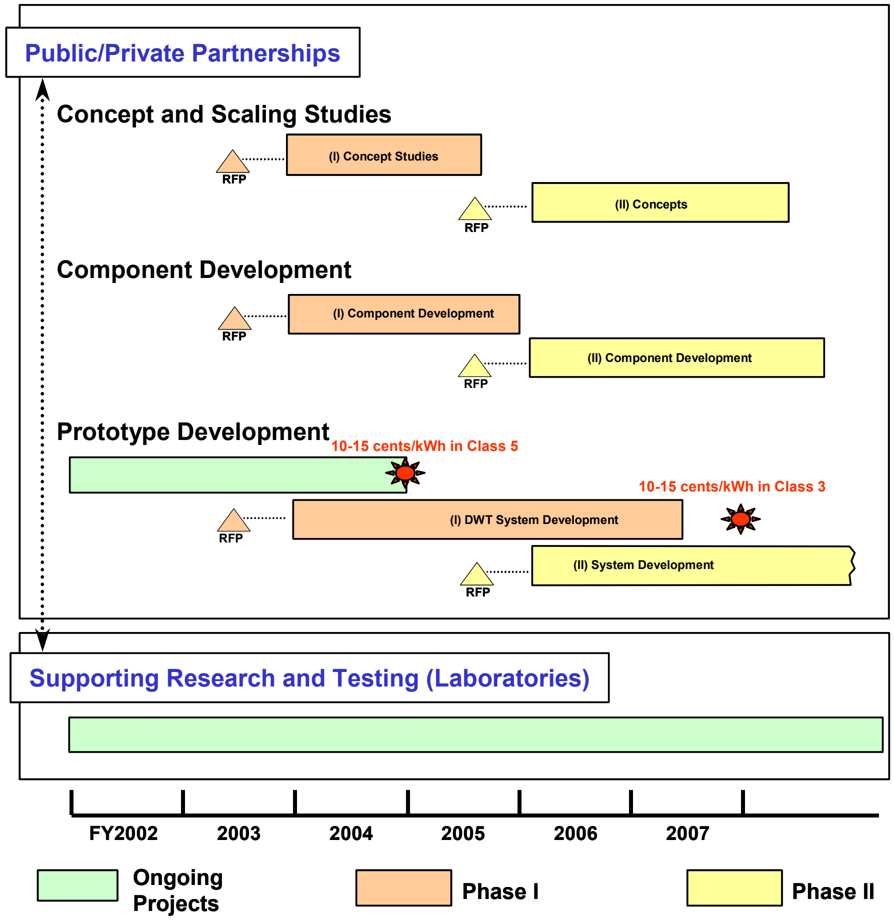


Figure 9. Distributed Wind Technology Strategy

electricity for specific small loads such as battery charging for sailboats and small cabins, to 3–15 kilowatt (kW) systems for a home, to those that generate up to 100 kW of electricity for large loads such as a small commercial operation. Small wind turbines can operate effectively in large portions of the rural areas of the United States. It is estimated by industry that small wind turbines could meet 3% of U.S. electricity consumption by 2020.

Small wind turbines (machines of <100 kW), though seemingly simple, must overcome many of the same technical barriers as those facing larger utility-scale machines. Because of the need for simplicity and high reliability, small machines face other technical challenges. The importance of understanding small wind turbine performance has been identified in previous Wind Program activities. However, many issues remain poorly understood when it comes to the specific behavior of small wind turbines, such as furling behavior, thrust measurements, yaw behavior, and blade and tower loads.

In June 2002, the American Wind Energy Association released its "Roadmap: A 20-year industry plan for small wind turbine technology." The Wind Program's plan for DWT activities incorporates many of the Roadmap's recommendations.

4.2.4 Research Activities

The DWT subkey activity is pursuing the same broad objective as the LWST effort – to reduce the cost of

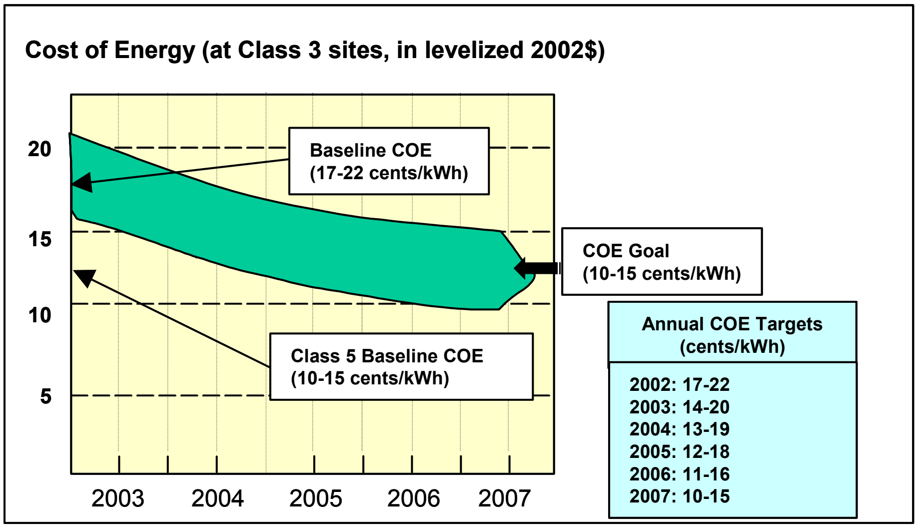


Figure 10. Distributed Wind Turbine Cost of Energy Tracking and Goals

energy of wind turbines (<100 kW for distributed turbine technology) at lower wind speed sites. In support of the DWT objectives, the program has announced a competitive solicitation for public/private partnerships to develop small turbine technology for lower wind regimes. The contracts with industry resulting from these public/private partnerships will be supported by a number of other necessary efforts, including design review and support, field testing, and laboratory testing.

The Wind Program coordinates its efforts with other elements of the Office of Energy Efficiency and Renewable Energy. In particular, the Distributed Energy and Electric reliability program provides support in the reduction of barriers to interconnection and utilization.

It is a substantial challenge to design, manufacture, and install small wind turbines that are low in cost and yet rugged enough to withstand 20 to 30 years of operation in weather that is often severe. Small wind turbine technology development is both art and science. The true measure of a new design is often not known until several years of operation at dozens of sites. At present, there is no way to effectively duplicate the wear and tear of the real world during the product development stage. As a result, reliability has historically been the Achilles heel for small wind turbine technology.

Activity Status – The program's support for distributed turbine technology builds upon prior cost-shared turbine development activities. In 2001, the program initiated the Small Wind Turbine Development effort. The competitive solicitation for that project led to the selection of four companies to pursue advanced designs. These four designs are in various stages of development and testing.

In FY2003, the program issued a solicitation for proposals under the first round of funding under the new DWT public/private partnerships. The public/private partnerships will work to enhance design techniques and capabilities, particularly rotor aerodynamics and dynamics that are unique to small wind turbines.

Technical Plan – The DWT project will be implemented through a sequence of open solicitations (two phases) for the development of advanced technology (Figure 9). Each of the solicitation phases will consist of three types of projects in which industry can participate.

- The first type of project is for conceptual design studies. Design studies offer an industry partner an opportunity to determine the probable value of a particular concept by performing a paper analysis before undertaking detailed design and fabrication. These small scale studies (approximately $200,000) are non cost-shared and the results are public domain. These studies are intended to lead a developer to the next round of solicitations where they may choose to more fully develop their idea. Industry has identified improved subsystem integration as being a priority.

- The second type of project is a cost-shared component development project. In this type of project, the industry partner completes detailed design and testing of an advanced prototype component or subsystem. Such components are expected to help reduce the cost of an existing design, or to serve as the basis for an entirely new prototype design. Based on current technology status, the program expects that component efforts may focus on advanced airfoils, permanent magnet alternators or generators, foundation/anchoring systems, and tower designs.

- The third type of project calls for the cost-shared detailed design, fabrication and testing of an advanced prototype turbine. These turbines will be tested in low wind speed environments that are representative of Class 3 conditions and demonstrate the likelihood of achieving the DWT goals.

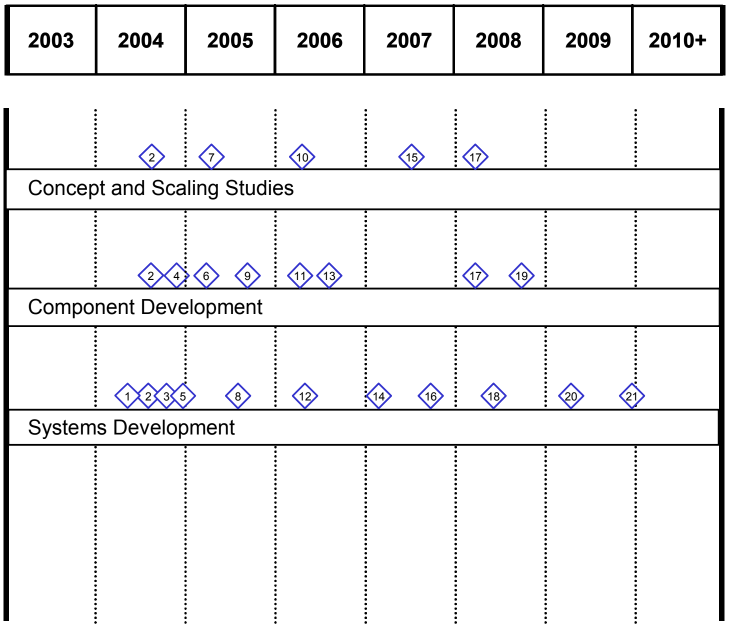
Each subsequent phase of solicitations offers an opportunity for a team that has developed a concept or component to complete their development cycle by developing a complete turbine prototype. This two-phased approach with three different types of projects allows the program to develop a broad portfolio of technologies and partners. Such a broadening of the technology base provides a higher level of likelihood that the goals and objectives will be met in the projected time frame. Conversely, all partnership efforts have clearly defined tasks and deliverables. Task reviews are established at key points in each project to allow termination or redirection of projects that are not achieving their goals.

In addition to the public/private partnerships, the program will pursue a number of research efforts that industry has identified in its Roadmap as being important for the ultimate success of small wind turbines. These are described in Section 4.3 “Supporting Research and Testing.” It should be noted that the Roadmap outlines a wide variety of efforts, many of which are policy-focused and beyond the role of the DOE program.

4.2.5 Milestones

Milestones for the Distributed Wind Technology subkey activity provide planning guidance and a means by which progress can be tracked.

Distributed Wind Technology



Milestones

1. Complete detailed design of two prototypes
2. Initiate 3 new grant projects
3. Begin testing of first DWT prototype turbine
4. Conduct Preliminary Design Review for one grant project
5. Complete NWTC site preparation for two prototype tests
6. Begin testing of one component under DWT cooperative agreement
7. Award grants/cooperative agreements for the second round of DWT solicitations
8. Test another small wind turbine to the suite of IEA tests
9. Complete all round one conceptual designs
10. Complete one grant for conceptual design studies
11. Begin testing of another component under DWT cooperative agreement
12. Seminar on small turbine test strategies for private firms that want to be in small turbine testing business
13. Evaluate final design reports for component development agreements
14. Begin testing of one DWT turbine developed under cooperative agreement.
15. Test another small wind turbine to the suite of IEA tests
16. Complete evaluations of turbine system development work under round one of the DWT solicitations.
17. New procurement for concept design studies, and component development.
18. New procurement for extended field testing for prototypes developed under previous solicitations.
19. Evaluate final design reports for component development agreements from Phase two of DWT solicitation.
20. Work with manufacturers to develop streamlined, cost reducing manufacturing strategies.
21. Develop a new solicitation to develop distributed wind turbines for markets and applications that have not been fully developed.

4.3 Supporting Research and Testing

The Supporting Research & Testing (SR&T) subkey activity supports the advancement of technology in those critical areas that have been shown to have the potential to reduce the cost of energy of large utility-scale and small distributed wind systems in low wind speed regimes. The SR&T effort brings specialized technical expertise, comprehensive design and analysis tools, and unique testing facilities to bear on problems that industry will encounter in bringing new wind technology to the marketplace.

4.3.1 Goal

The Supporting Research & Testing subkey activity provides targeted research and testing support to meet the needs of the Low Wind Speed Technology and Distributed Wind Technology research activities. Therefore, as a supporting activity, the goals of the SR&T effort are the same as the LWST and DWT subkey activities.

4.3.2 Technical Approach

Strategy

The strategy of the SR&T effort is to use the research staffs of the National Wind Technology Center (NWTC) and Sandia National Laboratories (SNL) to perform wind technology-specific research targeted to help industry improve the performance of components and fully integrated turbine systems. To that end, program researchers work closely with industry to define and prioritize those research activities that address their specific long and short term requirements. On occasion, program researchers may also contract with universities and other research organizations for SR&T efforts.

A Wind Turbine Pathways Analysis is used to guide the SR&T strategy, to identify areas of potential technology improvement and the specific research efforts required to achieve them. The Pathways analysis was introduced, in conjunction with annual COE tracking, in Section 4.1.2, and its application to SR&T efforts is further described below. The research and support activities are reviewed annually as part of the wind program peer review processes. Research that provides no direct link to achieving technology improvements is not pursued.

NWTC and SNL staff provide extensive design review, analysis and testing support for a broad array of industry activities including systems analyses, component blade and drive train tests in NWTC facilities, as well as validation of turbine prototypes in the field. These activities are closely coupled and directly assist industry in achieving design goals with hardware that will meet international design certification standards. These support activities are performed under the auspices of Cooperative Research and Development Agreements (CRADA) or as part of development subcontracts with industry.

Performance Measures

The success of the SR&T subkey activity, and progress in meeting its objectives, will ultimately be reflected in the progress made toward the LWST and DWT COE targets. Every research effort under SR&T has been linked to meeting these cost goals. As described in Section 2.4.1, the program has identified a set of Technology Improvement Opportunities (TIOs) that are expected to contribute to the lowering of the costs of large wind technology in Class 4 regions. Progress in realizing the benefits of

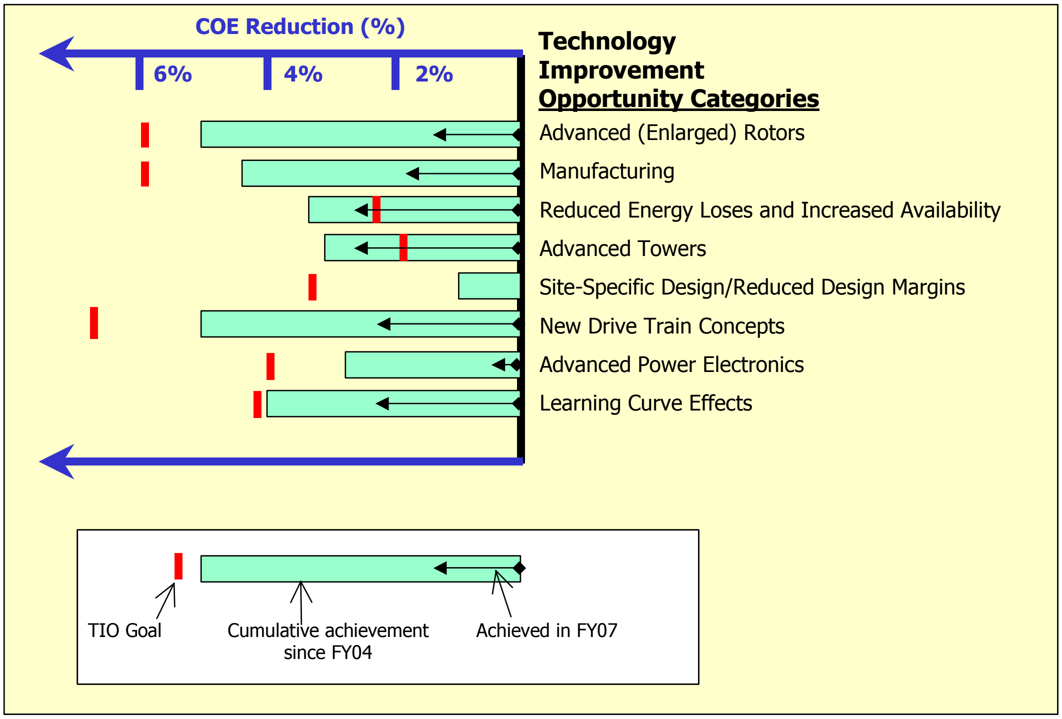


Figure 11. Tracking of Progress in Achieving Technology Improvement Opportunities (For illustration purposes, the example shown is for a report at the end of FY 2007)

those cost reduction opportunities will come from several of the program's subkey activities. In a similar manner, SR&T efforts will support the achievement of DWT goals.

Figure 11 shows how the program will track this progress annually. {The example shows how this assessment might look at the end of FY07. As such, it is meant to be illustrative of the process, and not meant to provide actual values. The annual assessment process will be documented each year in a separate program report.} The graphic shows the improvement in COE that each TIO category is expected to yield over the multi year technical plan time horizon (the "TIO goal."). The figure also shows the progress achieved since the 2003 baseline date (green bar) and the progress made in the example year of 2007 (black arrow). By tracking the progress in achieving the improvements offered by the TIOs, the program is able ensure that its investments in the public/private partnerships and the SR&T activity are achieving the desired benefits.

4.3.3 Technical Challenges

The challenges faced by industry in developing new technologies are many. Innovative or advanced technologies are expected to be major contributors to future machine designs. Technologies that address the opposing design requirements of weight, cost, and reliability are essential to wind's continued growth. Ultimately, a much better understanding of the design and safety factor tolerances driving cost and reliability must be achieved if advanced turbine system designs are to be truly optimized. SR&T research, in support of the LWST and DWT activities, targets those challenges.

In the 1970s and 1980s wind turbines used classical control designs to regulate power and speed. The methods used, however, were not always successful. These systems often had bandwidths large enough to destabilize low-damped flexible modes leading to high dynamic load fatigue failures. Modern turbines are larger, mounted on taller towers, and are more dynamically active than their predecessors. Control systems to regulate turbine power and maintain stable closed-loop behavior in the presence of turbulent wind inflow will be critical for these designs. New advanced control approaches and paradigms must account for low-damped flexible modes in order to reduce structural dynamic loading and achieve the 20-25 year operational life required of today's machines.

Program researchers can currently envision many potential technological responses to those challenges. For instance, advanced drive trains will incorporate rare earth permanent magnets for excitation. They will use novel drive train configurations such as reduced gearbox stages and low speed and medium speed generators. Advanced power electronics will allow variable speed operation while improving overall drive train and power conversion efficiency. Such power converters will also allow higher quality power for electrical grid connection. Advanced rotors may be field assembled, have a lower blade chord (width) and run at higher tip speeds to reduce rotor loads. They will be made from advanced materials such as carbon fiber, and may incorporate passive control mechanisms. Advanced controls will help to improve performance and reduce system loads while monitoring overall system health contributing to reductions in maintenance cost. Higher rotor blade tip speeds will challenge designers to reduce aeroacoustic emissions. To take advantage of higher velocity winds at higher altitudes, new towers will be developed that are less expensive, are made of advanced materials, and can be assembled onsite to reduce transportation costs. Such towers may also provide for self erection to reduce the significant costs associated with placing turbine nacelles on taller towers. Advanced designs must also account for poorly understood turbulence and velocity changes associated with nocturnal jets as they dip to within wind turbine operating heights.

In the area of offshore development, technical challenges include issues such as combined wind, wave and ice loading, geotechnical design issues (foundations, floating platforms, anchoring, and shifting ocean floor dynamics), and offshore transmission and interconnection issues. An improved understanding of the offshore environment, including impacts on avian populations and ocean mammals will be important. U.S. industries that specialize in ocean engineering, especially in deep water applications, will contribute a great deal of expertise in this arena. Every effort will be made to encourage teaming with these industries in developing and assessing these future applications.

The technology challenges for DWT are no less demanding. In addition to having the same environmental design constraints as larger turbines, DWT systems must be extremely durable and function without the highly trained maintenance professionals that typically supervise large wind farms. These systems must be designed and manufactured to provide 20 to 30 years of sustained operation at remote locations with only routine maintenance and support. Many of the design tools developed, and much of the research done to-date has been targeted for larger systems. As a result, significant technical issues including load control, furling performance, aeroacoustic emissions and power electronics reliability remain unresolved. All of these factors contribute to critical system performance and reliability issues, which left unresolved, will be a significant barrier to future small system deployment.

4.3.4 Research Activities

The program's portfolio of SR&T projects supports the cost reduction goals of the LWST and DWT subkey activities. Table 3 outlines the SR&T research portfolio.

Enabling Research

Taking turbine designs to the limit of cost and performance will require advances in several research disciplines. While some of the near-term cost of energy reductions may be possible, based on current levels of technology (e.g., tall towers), others will require investment in fundamental research to be successful.

Table 3. SR&T Research Portfolio
Enabling Research

• Advanced Rotor Development
  • Blade development
  • Aerodynamic code development and validation
  • Aeroacoustics research and testing
• Site-Specific Design
  • Inflow characterization
  • Design load specification
• Generator, Drive Train and Power Electronics
• Systems and Controls
  • System design tools
  • Controls design and validation

Design Review and Analysis
• LWST Public-Private Partnerships • DWT Public-Private Partnerships
Testing Support
• Structural Testing • Dynamometer Testing • Field Testing

Enabling Research activities, which support the LWST and DWT programs' goals, fall within four major topic areas: Advanced Rotor Development; Site-Specific Design; Generator, Drive Train and Power Electronics Efficiency Improvements; and Systems and Controls.

Advanced Rotor Development – The rotor of a wind turbine is a completely unique component. The rotor's blades control all the energy capture and almost all the loads, and are therefore a primary target of advanced rotor, enabling research efforts. The challenge to be met by rotor development efforts is to create the scientific knowledge base and engineering tools to enable blade designers to achieve optimum performance at the lowest possible cost, using new materials, improved manufacturing processes, and enhanced design tools. This work will assist the industry in meeting the LWST and DWT goals by stretching rotors to greater swept area in previously un-economic wind regimes.

Advanced rotor development work can be segmented into three subtask areas:

1) Blade development
2) Aerodynamic code development and validation
3) Aeroacoustics research and testing

Each of these subtasks is an important part of program support to LWST and DWT progress, and all three will play continuing important roles over the planning period.

<u>Blade development</u>: A significant step toward the LWST and DWT goals will likely require blades that are stiffer and stronger to span the greater area, while lighter and adaptive, to reduce system loads. Beyond that, design details need to be evaluated so that the entire industry is led in the direction of efficient material usage. Finally, substantial testing, both in the laboratory and in the field, is required to validate the tools, loads, and designs, and to make sure they can be linked to the site characteristics.

The first step in blade development is gaining a basic understanding of the new materials that are likely to be used in the blades of the future. Traditional blade materials have been based on fiberglass technology typical of the boat-building industry. The next generation of machines will require longer, thinner, and equally durable blades using stiffer and stronger materials, such as carbon fibers. The program will characterize carbon's capabilities and how it interacts with the glass and other materials. The program will also explore further materials options, including resins, fiber treatments, and the effect of manufacturing processes on material properties. Full blades will be manufactured by industry partners (often at a subscale to limit research cost) to evaluate material performance in the as-manufactured state. The program will help develop sophisticated engineering tools that provide the ability to mold these materials into a working structure of minimal cost, manufacturable design, and adequate durability. The program will also continue to explore new blade shape designs that may help reduce loads and stresses, and thereby increase durability. It will then be possible to not only evaluate individual designs, but to describe how design practices should be tailored to take into account material interactions, property variability, and specified design loads.

Aerodynamic code development and validation: Aerodynamic code development and validation is working to overcome the fact that the current generation of aerodynamic loads/performance codes fail to adequately predict steady or unsteady loads in the near- and post-stall operating regime. Performance predictions currently rely on two distinct approaches. The first couples 2-D airfoil performance data obtained either empirically from wind tunnel or field measurements and/or through analytic computations with momentum theory. The 3-D loads for a rotor are obtained by integrating the 2-D sectional performance along the span, adjusting the inflow and balancing the momentum flux. The benefit of this approach is an extremely fast computational time, permitting numerous iterative design permutations in almost real time. Unfortunately, details of the actual 3-D flow characteristics are ignored. In near and post-stall operation, where the flow is strongly three-dimensional, large discrepancies between actual and predicted aerodynamic performance occur. The second approach is to perform full 3-D Navier-Stokes analyses on the full rotor. Although Computational Fluid Dynamics (CFD) codes have been used extensively for helicopter and aircraft analyses for several years, the adaptation of these codes to model wind turbine rotors has only recently been attempted and is in the preliminary evaluation phase. This method will provide a detailed characterization of the underlying 3-D fluid physics driving turbine rotor performance in the near and post stall regimes for both steady and unsteady inflow conditions. However, CFD is unlikely to be used as a principal design methodology in the near future due to the extremely long computational times required for every design set point.

As model enhancements are made, the program will compare both approaches with field and wind tunnel test data in order to improve current design codes. Researchers expect that computational runs of the full 3-D codes will provide significant physical insight into the underlying separation processes in near- and post-stall operation. Based on these insights, the adaptation of new theory integrated into existing momentum and aerodynamic codes. Data that the program previously obtained from testing the highly-instrumented NREL Combined Experiment Rotor (CER) in the NASA-Ames 80x120 wind tunnel will be used to validate CFD results, theory, and improvements to the existing design codes. By empirically “tuning” the resultant aerodynamic codes, the limitations and performance errors derived from 2-D flow assumptions for a strongly 3-D turbine rotor application can be overcome without significant impacts in code run times. Results will enable more efficient design of both LWST and DWT rotors.

Aeroacoustic Research and Testing: Turbine noise can be caused by rotor speed, blade shape, tower shadow, and other factors. The program is sponsoring both wind tunnel and field tests to develop a semi-empirical noise prediction code that will be useable by LWST and DWT manufacturers to ensure that new rotor designs and full systems have acceptable noise signatures. High-growth domestic markets for small wind turbines will demand quieter rotors, especially when turbines are sited in residential neighborhoods. Small turbines operate at high rotational speeds and tend to spin even if they are furled (pointed out of the wind). Aeroacoustics research activities will be conducted to explore how to reduce noise produced by distributed wind turbines in a variety of wind regimes, and to develop a noise standard with industry participants that can be used for the growing domestic DWT market. This research will support the DWT and LWST public-private partnerships, both directly in working with industry and indirectly in providing necessary underlying research.

In the longer term, program researchers will work to develop physics-based aeroacoustics codes for both design and problem solving applications. These will enable more-slender blades and higher tip speeds, enhancing both cost and performance of future designs.

In summary, the rotor development activity under SR&T is closely tied to the LWST and DWT component development public-private partnerships, and will be an important contributor to expected reductions in COE. Program researchers are providing support in material analysis, blade design and analysis, and blade manufacturing. Future activities will use a cyclical approach whereby sub-scale blades and subcomponents using advanced materials and shapes are designed, built, and tested. Testing will include non-destructive approaches that can determine failure initiation and internal responses. Program researchers will enhance fatigue, material failure, and reliability analysis capabilities. In the longer term, research is expected to lead to small, integrated smart actuation devices for load alleviation and performance enhancement.

Site Specific Design – Future wind energy installations will be in areas of significantly different wind resource potential and roughness. Installations of onshore turbines will need to move into areas of lower resource, using taller towers and longer blades to harvest the more rarified energy. To continue to design for loads characteristic of more-energetic sites would drive up the cost unnecessarily and limit wind's cost-effectiveness in other areas. The benefits of designing large installations (100 MW or more) for specific site conditions are substantial. The nature of atmospheric loading at increasing heights will be assessed and documented. Blade designs, including aerodynamic geometry, controls, and structural details, need to be tuned to the energy capture requirements and durability suitable for low energy and lightly loaded sites. Every structural strength requirement throughout the system is based on the expected maximum event and turbulence at the site.

The offshore installations will operate in a very different environment, over a wide range of energy densities. These turbines must be designed knowing, in detail, the nature of the offshore winds (higher energy, lower turbulence) and the effects of wave and current loadings at the base. Existing approaches to design specification are not capable of providing a complete designation of such site design conditions.

This subtask, therefore, covers two areas. The first is the development of systematic methods for specifying specific site energy and load conditions. The other area is to conduct the field measurements that validate the methods, and to work in public-private partnerships to collect the site-specific information in important regions of the country, both onshore and offshore.

Inflow Characterization: A significantly better understanding of the wind resource and the nature of inflow and its impact on turbine performance and reliability must be achieved. A clear understanding of the nocturnal jets encountered at sites in the Great Plains is critical. (The nocturnal jet is a poorly understood phenomenon that occurs at night as cooling allows high level higher elevation high velocity winds to dip close to the earth's surface, creating violently turbulent wind regimes.) New components and architectures, which reduce structural loads while increasing performance and energy output when operating in these inflow regimes, must be explored. Design and performance codes must continually improve if LWST and DWT technology innovation is to be sustained.

Design Load Specification: The inherent uncertainties of site conditions, turbulent winds, extreme events, and component strength must all be accounted for in a manner that does not require overly conservative design margins. International standards have traditionally specified safety factors when operating in these inflow regimes for environments intended to envelop the worst-case situation over broadly defined site classes. As turbines are routinely designed for specific sites, where these standard load cases can be reduced and tuned to site-specific conditions, the ability to estimate and account for individual design uncertainties will become a necessity. Not only will site-specific design margins be needed to avoid a catastrophic loss of a wind plant, but increasingly sophisticated financial institutions will require it for due-diligence before investing in large installations. Methods of estimating and designing to site-specific environments with uncertainty-based design margins will be established and integrated into standard design practices.

Generator, Drive Train and Power Electronics Efficiency Improvements - The generator, gearbox and power converter represent roughly 25% of the installed capital cost of a modern wind turbine. Generators have historically been based on wound rotors or squirrel cage induction designs, but such generator designs may not be the ideal design for wind turbines of the future. The drive train is becoming a major driving factor in machine design because its weight and size affect other wind turbine configuration and erection factors, such as tower size and crane rating. Variable speed wind turbine designs are highly dependent on the efficiency and mode of operation of the power converter that changes variable-frequency AC from the generator to fixed-frequency AC that is properly conditioned for injection into the electrical grid. Conversion efficiency is highly important in these designs.

Future designs of generators and power converters must be specialized and tailored to wind turbine operation because wind turbines operate the largest percentage of their time at less than rated power. The use of permanent magnet generators that are more compact and have higher flux densities will be important for future designs, as will power converters and generators that allow variable speed operation and have higher efficiencies at below-rated power. Of further importance is reliability of all components, since the generator and power converter are key points of failure in the total system. This task will explore key enabling research areas that will contribute to LWST public/private partnership improvements in converter and generator designs, focusing on generator and converter architecture, controls and reliability.

Systems and Controls – Systems and controls research is focused on a rapidly advancing area of technological innovation that offers significant potential advantage in reducing the cost of wind-generated energy. New innovative strategies are being applied to the way that wind turbine components are moved or controlled. This includes control of conventional turbine components (such as blade pitching), new components (such as twist-coupled blades), and advanced devices (such as micro-tabs). The control strategies have to be designed to meet two seemingly conflicting goals – to increase energy capture, yet reduce turbine structural loading.

LWST and DWT machines of the future will be dynamically active and must be carefully designed to mitigate unwanted structural dynamic loads and responses. New innovative rotor control strategies will be developed to mitigate the imparting of unwanted aerodynamic loads into the turbine structure. Studies indicate that low wind speed technology (LWST) goals can be met if wind energy technology moves toward large slender turbines placed on tall towers. Designing these large structures to be long lasting and fatigue-resistant at minimal cost is a difficult task. The chances of wind turbines experiencing unwanted dynamic responses and instabilities increase with height and flexibility. In addition, loads due to wind fluctuations will likely increase as rotors are placed at greater heights above ground where there is increased risk of coherent turbulence. These new machines must therefore be very carefully designed to mitigate unwanted structural dynamic loads and responses. While the rotor itself can be made more cost effective through innovative approaches to control, the entire wind turbine system is the expected beneficiary, as loads are reduced everywhere on the structure.

Recent advances in three major areas of technology are being combined and applied to provide new control strategies. First, ongoing evolution of wind turbine modeling capabilities within the Wind Program enable complex structural dynamic responses to be more accurately simulated and predicted. Second, there have been major recent developments in “state-space” control methods (and associated computer software algorithm development tools). These methods can be utilized in control paradigms to provide promising load-mitigating control strategies tailored to wind turbine technology. Third, improvements in computer hardware technology now enable data rates and control algorithm execution speeds at levels needed to successfully combine and apply the two capabilities described above. Application of the resulting control strategies, coupled with new components and advanced devices from LWST and DWT efforts, will enable turbines to be operated and controlled in innovative ways. Studies indicate that successful development of theses innovative control concepts are a major contributing factor in meeting the public/private partnership COE goals.

The program has a suite of advanced codes that will be used for modeling wind turbines of arbitrary complexity and extracting state-space matrices for turbine or controls design. Program researchers also have an extended range of analysis capabilities not previously available, e.g., operating modes computation, trim, nonlinear controls simulation, and aeroelastic stability analysis. In the short term, work will be undertaken to enhance the integrated system capability of these codes by introducing two new features: a) composite blade dynamic modeling capability and b) multivariable-controls-design-specific interface. In the future, this will be applied to the modeling of two wind turbines: a 3.6 MW wind turbine and a conceptual offshore wind turbine.

The importance of understanding DWT performance has been identified in previous Wind Program activities. However, many issues remain poorly understood when it comes to the specific behavior of small wind turbines, such as furling behavior, blade loads, and the effect of furling on turbine performance. Small wind turbine manufacturers have historically relied on variable geometry testing approaches to design for furling, tail boom lengths and tail sizes, and other related small wind turbine design parameters. It is generally agreed among small wind turbine experts that modeling small turbine furling from an aerodynamic perspective with today's tools has a high degree of uncertainly, due, in part, to a lack of quality data on small turbine loads and operational behavior. The Small Wind Research Turbine (SWRT) was designed and built in FY 2003 and preliminary testing was conducted to start to provide data for the wind industry and wind turbine modeling community so that small turbine operation can be better understood. Over the next several years, this project will provide quality data on how small wind turbine design parameters affect turbine operation. State-of-the-art models, including ADAMs and FAST, will be constructed for the SWRT turbine and compared to the test data to further the capability of these models to predict small turbine operation.

Operations and maintenance costs have continued to drop as manufacturers and operators gain experience in manufacturing, installing, and maintaining wind turbine plants. After the low hanging fruit of improper component selection, inadequate maintenance practices, and poor installation have been harvested, it will still be necessary to drive down field maintenance costs. This is especially true as turbine size increases and the installations move offshore. Not only do the site conditions change – low level jets, tower wave, loading and corrosive wave environments – but the cost of each maintenance interaction becomes prohibitive. Methods for health monitoring and preventive maintenance will be created to mitigate the effects of increasingly more difficult operations.

Design Review and Analysis

As the Wind Program invests in the development of new technology through cost-shared contracts with industry under the LWST and DWT subkey activities, it will also be providing oversight and technical support to those activities. The Design Review and Analysis (DR&A) effort provides a means whereby NREL and Sandia staff provide specialized expertise to the industry-led activities. It also provides support to the necessary proposal evaluation process. This support and oversight not only assists industry, but also protects the Wind Program's investment in these partnerships and enhances their chance of success. DR&A services are an integral part of the phased subcontract structure for LWST and DWT turbine development activities, and are provided as support functions at the request of industrial partners.

Testing Support

An important part of the development of advanced turbines is computer modeling and dynamic simulation. However, validating and improving these models is very difficult because the models cannot always simulate true inflow, turbine response or control performance. To fill this gap, it is necessary to perform extensive, detailed field-testing and to utilize the data collected to improve both the control algorithms themselves and the simulation codes from which they were designed. Tests are conducted on operational turbines in the field, and on a wide range of full-scale turbine components in specialized testing laboratories.

Structural Testing - The NWTC structural test facility has been operating since 1990. This facility has been used primarily for testing full-scale wind turbine blades for Wind Program subcontractors and wind industry partners. The present capabilities include fatigue testing, ultimate static strength testing and several non-destructive techniques, such as photo-elastic stress visualization, thermographic stress visualization, and acoustic emissions. Rapid growth in the size of wind turbines has strained the capacity of the existing structural test facility to its limit. The facility is unable to test the next generation of blades. Many of the proposed LWST projects, as well as current industry development, exceed the size and load capacity of the existing facility. Multiple large blade failures on field-deployed turbines – weighing over 10-tons each – would not only be dangerous, but would undermine industry credibility and hinder reaching DOE's COE objectives.

During the planning period, the Wind Program expects to build a 70-meter blade facility. This new facility will be constructed at the NWTC and will be co-located with the existing facility. The new facility will have the capacity to test multiple blades simultaneously. Both the current test facility and the 70-meter facility will be available for turbine testing into the next decade, and will be essential in meeting the LWST goals.

Dynamometer Testing - The 2.5 MW Dynamometer and Spin Test Facility at the NWTC is a test bed dedicated to the testing of wind turbine drive trains, drive train components, and power systems. The project began in 1995 as a result of wind industry input that a facility of this type was needed. The facility was completed in August 1999. The NWTC staff currently conducts tests such as gearbox fatigue, wind turbine control simulations, transient operation, generator and power system component efficiency and performance for the advancement of the U.S. Wind Energy Industry. Previously, the only way to verify operating integrity throughout the turbine's full load envelope was to test a field prototype under severe conditions. This NWTC facility provides improved methods for full-system testing of wind turbine systems to identify critical integration issues before field deployment. This unique facility gives the U.S. industry an edge over strong European competition.

The Wind Program plans to maintain its leadership role in wind turbine drive train testing and meet the needs of the emerging multi-megawatt industry with a two-pronged approach. First, the existing 2.5-MW facility will be fully supported to operate at maximum capacity into the foreseeable future, meeting the needs of current turbines in the 1 to 2-MW size range. Secondly, a new 5-7 MW dynamometer facility will be constructed beginning in 2005 to test the upcoming multi-megawatt wind turbine generation. Tests will be performed to verify gearbox design conditions, evaluate new low-speed permanent-magnet direct-drive generator technology, and test innovative power electronic devices proposed under the LWST project. This facility is anticipated to be available for industry testing in 2006.

Field Testing - Field testing supports a wide range of LWST and DWT activities. Such testing is typically conducted on full-scale turbines installed in the field, although it is also done on components and subsystem test articles. Field testing necessitates installation of sensors and transducers (e.g. strain gages, accelerometers) used to quantify loads on operating turbine structural components, noise emissions, output of electrical systems, and meteorological inflow conditions. The test devices are connected to special ruggedized computer-based data acquisition systems. The large quantities of resulting data often require specialized processing and analysis to extract required information. Field tests measure turbine loads, acoustic emissions, power production, and power quality. Resulting loads data are essential in verifying computer simulation models of wind turbine configurations. Field test data are especially important for assessing the viability of new, innovative turbine configurations, since models of such configurations often need tuning with test data to establish necessary confidence levels.

Accredited turbine field data are essential inputs to design evaluations required to support certification and due-diligence activities. For wind turbines to be successful in the marketplace, both domestically and internationally, they must meet international standards for reliability, and must ultimately the certifiable by standards bodies. The collection of reliability data in the field helps manufacturers identify evolutionary technical improvements.

Future testing activities that will improve the reliability and durability of wind turbines include:

- Developing improved life-cycle testing protocols and analytical methods;
- Developing a better understanding of design load characterization for enhanced reliability, durability and longevity;
- Performing durability and reliability testing for environmental extremes; and
- Identifying design elements necessary to achieve 20+ year operating life.

4.3.5 Milestones

Milestones for the Supporting Research and Testing subkey activity provide planning guidance and a means by which progress can be tracked.

Supporting Research and Testing

Milestones

1. TBD (Target date 1/31/03)

5.0 Technology Application

The Technology Application key activity area addresses the many non-technology barriers to the use of wind energy systems. These barriers and opportunities are different for the different size machines, as shown in Table 4.

Table 4. Wind Turbine Market Segmentation

Turbine Size Range	Applications	Barriers
Small (<10 kW)	Residential, off-grid	Zoning, integration into new applications
Intermediate (10 kW - 500 kW)	Wind/diesel, industrial	Power quality, control and stability, storage, zoning
Large (500 kW – 5 MW)	Grid Interconnect	Transmission and access and operational impacts
Very Large (>5 MW)	Off-Shore Grid Interconnect	Cables to shore, viewshed, regulatory framework, power system integration

The Technology Application key activity encompasses three subkey activities: Systems Integration, Technology Acceptance, and Systems Engineering and Analysis. Table 5 provides the budget assumptions made in preparing the Technology Application plan. Because final program funding allocation decisions are made annually by the Department of Energy, these values are likely to be adjusted each year. They do, however, provide a general sense of anticipated funding trends, consistent with meeting the goals described in this chapter.

Table 5. Multi Year Funding Profile for Technology Application (millions $)

Subkey Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Systems Integration	3.2	3.2	3.8	5.0	6.0	6.5	7.4
Technology Acceptance	3.6	4.0	3.4	2.9	1.9	1.4	0.0
Supporting Engineering and Analysis	4.0	2.6	2.6	2.6	1.6	1.6	1.6
Total	10.8	9.8	9.8	10.5	9.5	9.5	9.0

5.1 Systems Integration

The Systems Integration subkey activity is working to facilitate the adoption of equitable grid access and operational rules for wind in all major regional wind markets, and to ensure that wind's needs are considered in regional transmission planning processes.

5.1.1 Goal

The goal of the Systems Integration activity is: "By 2012, complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs."

5.1.2 Technical Approach

Strategy

The Systems Integration subkey activity strategy is to assist regional electric system planning and operations personnel to make informed decisions about the integration of wind energy into their systems. Three primary targets have been identified: 1) Technology Characterization and Data Collection; 2) Tools and Methods Development; and 3) Application and Implementation. Program personnel will work with organizations such as Independent System Operators, Regional Transmission Organizations, the Federal Energy Regulatory Commission, and state and local utility planners to have wind considered in their deliberations and rulemaking proceedings in a fair and equitable manner. The program coordinates closely with the American Wind Energy Association, which is particularly proactive in this area due to its potentially crippling implications for future wind development.

A regional focus has been adopted because of the emerging importance of regional planning entities in electric system planning and market operation. Because wind program personnel will not ultimately be responsible for the decision making of these organizations, the program's strategy is to define and complete activities, on a region-by-region basis, that provide system operators, planners, and relevant decisionmakers with the information and tools needed for equitable treatment of wind power in the energy marketplace.

The Wind Program believes that a major public good is served by providing unbiased data about operation of wind energy in electric power systems. Wind energy saves fuel and O&M cost, provides jobs, and provides an alternative source of energy, thereby providing national security benefits. Electric utilities, State and Federal regulators, members of environmental groups and the ordinary taxpayer receive benefits from these activities that would not be provided by the private sector alone. The program will sponsor research and collect operational data when a major public benefit exists. In other cases, the principal responsibility may lie with wind turbine manufacturers and power system operators in developing simulation models for wind turbines. In such cases the program may still play a facilitating role. In still other cases, primary responsibilities must lie with regional stakeholders, power system operators and regional regulators in developing transmission plans to accommodate wind, while the program will provide supporting technical data and encourage fair treatment of wind.

Performance Measures

Progress in this subkey activity will be measured by examining the sufficiency of program accomplishments in each region of the country. Under Systems Integration, the program will provide technical support in electric power market rulemaking, the assessment of interconnection impacts, the development of tools to guide operating strategies, and the conduct of transmission system planning. When the program efforts in these four areas are complete, the program's efforts will be judge to have been successful. The completion of program activities is not predicated upon acceptance of, or implementation by, the stakeholders of any of these program outputs, since the program can only make support and tools available for use, but cannot directly influence whether they are adopted by regional planners and operators.

Figure 12 shows the process that will be used to assess this subkey activity's progress in reaching its goal. A Systems Integration expert group will assess the progress and status of each region in achieving the four areas outlined in the Systems Integration goal. After performing the regional status assessment, the group will judge the extent to which program efforts are complete. The expert group will consider the relative importance of program efforts in each region, recognizing that some regions have greater wind potential than others. The group's assessment will also be used to guide and refine planning for the program's systems integration activities in each region.

5.1.3 Technical Challenges

The electric industry is in a challenging period characterized by changing market rules and regulatory oversight, corporate restructuring, high competition, and technological change. The integration of renewable energy, including wind energy, into its supply mix, is one of many issues the industry is grappling with before it can move fully into this newer, more competitive market structure. The installed capacity of wind power has increased steadily in the United States and throughout the world. Research and development efforts by the industry and government have made wind energy competitive with that of traditional fossil-fuel generation in many locations. With the aid of various state policies and the emerging green power market, thousands of megawatts of wind power plants, of various sizes, have been built in the United States over the past few years. This trend is expected to continue in light of increasing environmental concerns, hydropower shortages, and swings in natural gas prices.

As a result of these developments, more utilities are seriously evaluating wind power. However, these utilities are also concerned about possible impacts on system operations when a large amount of wind power is introduced into the electric power system. There concern is despite the fact that, by the end of 2002, some 4,500 MW of wind generating capacity had been installed in the United States, 13,000 MW in Germany, and 32,000 MW worldwide. Their concerns are also despite the fact that wind energy and cogeneration sometimes total as much as 30 percent of instantaneous generation in Denmark. Utility decisionmakers, state regulators and investment bankers are unfamiliar with wind, and, therefore, overly cautious in their view of wind power as a utility generation asset. Principal among their concerns are potential system effects due to the current limitations in wind forecasting and the potential electrical system stability and dispatch implications. Their concerns, if not adequately addressed, could significantly limit the development potential of wind power in this country.

Since the inception of the program in the early 1970s, wind energy has generally been considered as a fuel-saver. That is, the primary economic and environmental benefit of wind energy is to reduce fuel consumption by other generators. Wind energy also displaces related operating and maintenance efforts and can enhance system reliability at times of system peak, on a statistical basis. However, as a consequence of the intermittency, utility operators often mistakenly assume that the full output of a wind plant can be lost at any second, and thus capacity for the full wind farm output must be on reserve. Wind's relatively low capacity factor (25 to 50 percent) suggests that for transmission service, which is usually priced in terms of $/MW-year, wind would have difficulty competing with a baseload option. In addition, renewable sources like wind are often located away from load centers, increasing relative transmission requirements compared to conventional sources. Another aspect of intermittency that

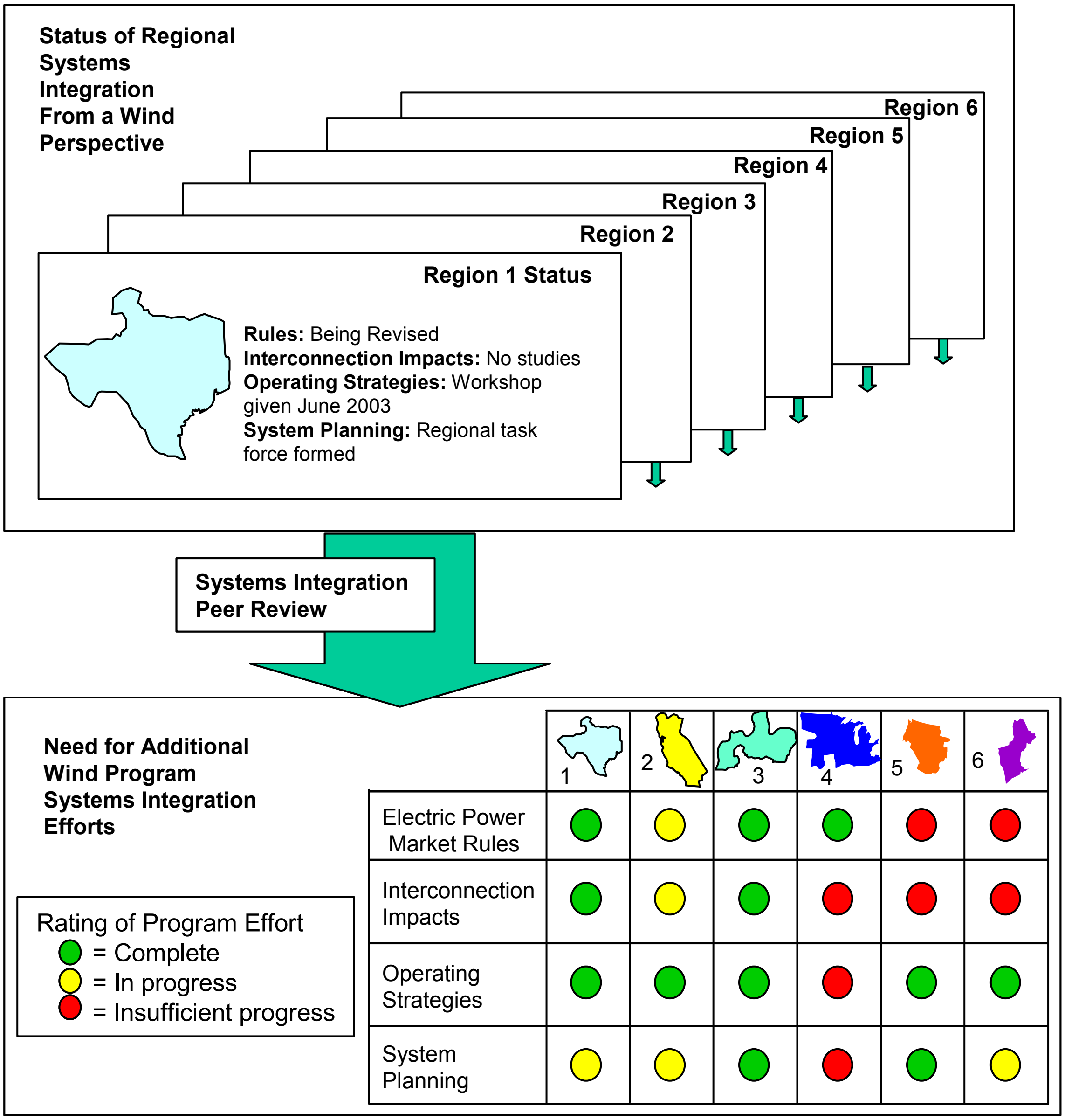


Figure 12. Regional Assessment of Systems Integration Progress and Peer Assessment of Need for Continued Program Role (Illustration of process)

disadvantages wind energy is that scheduling of generation service, normally required one day in advance in deregulated markets, is difficult for wind plants because of inherent limits in the ability to forecast wind plant output 24 to 72 hours in advance. Conventional units can be turned on or off based on operator's decisions, whereas a wind project requires the wind to generate power.

In the early days of the wind program, it was generally accepted that only a small fraction of energy on a power system could come from wind plants. A rule of thumb was five percent. Later, more detailed studies that looked at explicit representations of risk, wind power and impact on utility operation suggested that the five percent figure was only a conservative limit and that greater penetration could be achieved if power system operation were changed to accommodate wind energy. However, even at the five percent level, there is sufficient regulating capacity in typical utilities to compensate for the total loss of a typical wind plant. As instantaneous wind energy penetration increases on a system, the units operating on economic dispatch are backed off, i.e. fuel is saved, while those units that compensate on a minute by minute basis for imbalances between load, generation and exports (units on regulation) must vary their operation more frequently. Recent data suggests that the impact of typical wind projects on the need for regulation is small. In several senses the deregulated environment creates a tougher competitive situation for wind energy. With the advent of electric utility restructuring, the regulation service is provided at an additional cost by the wind plant operator. Prior to restructuring, regulation was provided as a service by the power system itself at no additional cost to independent generators.

5.1.4 Research Activities

Wind power is a unique source of electricity. The natural variability of the wind resource raises concerns about how wind can be integrated into routine grid operations, particularly with regard to the effects of wind on regulation, load following, scheduling, line voltage, and reserves. A lack of understanding of these areas is inhibiting market acceptance and hindering increases in the amounts of wind power. System costs associated with variability are only now being analyzed. The impact of higher penetration, and potential mitigation measures, are not currently being approached systematically. In addition, current transmission tariffs and grid operational procedures do not recognize wind characteristics, and, therefore, often unintentionally create deployment barriers. Despite these challenges, grid reform associated with FERC rules and RTO development presents an opportunity to work toward removing barriers. Various utilities and the Utility Wind Interest Group (UWIG) have taken lead positions in analyzing these issues, but a wind program framework for ensuring technical accuracy and advancement of methods is needed.

Technology Characterization and Data Collection

Wind Generator Modeling – The program is working with the wind industry to provide utilities and grid operation organizations with better wind generator electrical models to evaluate interconnection and system impacts of proposed wind farms. Without these, the grid evaluations will use generic induction generator parameters, and the amounts of wind capacity that will be allowed access to transmission interconnection will likely be unnecessarily low. By using non-wind-specific models, these organizations will not capture the advantages of variable speed power electronics, including their ability to provide VARs and their fault ride-through capability.

Current efforts in this area include support for ERCOT's development of an initial set of detailed software models of the different classes of commercial wind turbines. Although somewhat rudimentary, these models represent an important beginning of better wind turbine representation. The program will support future validation and training efforts, and improvement of these models as the validation process proceeds. An important goal of this effort is to encourage the use of these models in other regions.

The program has examined, with SCE, transmission limitations in the Tehachapi region of California, to better understand the effects that the current installations of induction turbines are having on the operational stability of that region. The goal is to develop a better understanding of the interaction of wind generators on the local grid operation, and to identify ways to mitigate the specific operational issues confronting that region.

Wind Farm Data Monitoring –The principal concern by electric utilities unfamiliar with wind energy is that the plant output can suddenly fall to zero. Data on the second-by-second power fluctuations from commercial wind farms has not historically been available. However, the program's ongoing cooperation with FPL Energy at Lake Benton II (MN) and Storm Lake (IA) has begun to provide excellent data to fill this need. Without long-term data sets from various wind resource regimes, evaluation of the grid impacts of variability cannot be performed. The data gathering effort has recently been expanded to include not only Minnesota and Iowa, but plants in Texas, the Northwest, and California. The data for the Northwest is being collected in cooperation with Bonneville Power Administration. Over the coming years, locations

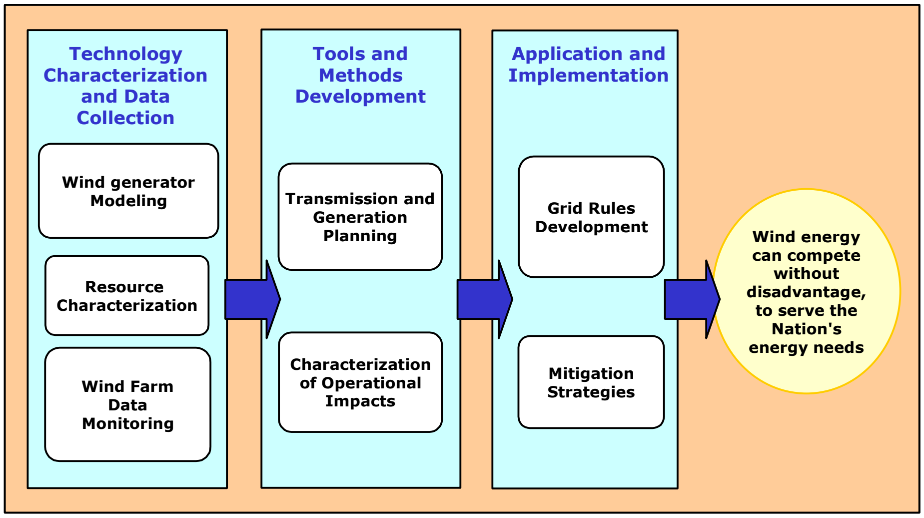


Figure 13. Systems Integration Research Plan

in Colorado, Wyoming, and other states will be added. The program will publish statistical data reports that will become a public reference for the future development of wind farm impact models.

Resource Characterization – The program will work to provide representations of the wind resource, including seasonal, diurnal and hourly shapes, where possible, to allow models to better characterize the potential benefits and impacts that wind can have on system operation, and to assess availability of transmission. Many of the same time series data bases used in validation of recent state maps can provide a basis for this new effort. The data collected in the wind farm modeling effort will also contribute to resource characterization. Over the next few years, the program will expand the resource characterization effort to include more sites, with different characteristics, and will ensure that this data meets the needs of the wind forecasting work described later in this section.

Tools and Methods Development

Grid Operational Impact Analysis – The wind program will address the variable, normally uncontrollable nature of wind power plant output, and the additional needs that its operation imposes on the overall grid. At present, the generation and transmission operational impacts that occur due to wind variability are not well quantified. At lower grid penetrations, these impacts have not generally been an issue. This research will include efforts to quantify and fairly allocate impacts in both an engineering and cost sense. Analysis methods of analysis are at an early stage of development. Without realistic analysis and cost allocation, utilities often tend to overestimate wind's operational costs, resulting in the undervaluing of wind power in the system. Unrealistically high ancillary cost evaluations will result in lower wind deployment rates.

A recent study of the Xcel grid indicated that an additional 300 MW of wind would impose an additional cost of around $0.018 cents/kWh of wind energy produced. This level represents a penetration of about 5% of the Xcel grid capacity. PacifiCorp has estimated an additional cost of $0.005-0.006/kWh for integrating 2000 MW, or nearly 20% of its capacity, of wind on its grid. The program plans to sponsor the development of methods for integrating these results into utility and regional operating assessments.

The program also sponsors an outreach activity to work toward the adoption of the rules and techniques developed in the analytical portions of this effort. This outreach function is essential if the benefits from this technical activity are to be realized.

Transmission and Generation Planning – Continued growth in electric loads results in the need to plan for and install new generators and transmission lines. Wind generation is a relatively new wholesale power source, so planning organizations and methods do not generally include wind in their planning. Future utility resource plans and regional planning efforts should include wind stakeholders in the overall process. Characterizations of potential wind resource locations and power delivery profiles are critical to the accurate assessment of potential transmission line upgrades or expansions. In addition, the reliability characteristics (capacity credit) resulting from wind and utility load temporal profile matches affect the valuation of wind in planning processes. Most of the foregoing can be handled by existing utility practices, as long as the required data is available.

The problem for wind developers is that existing practice for interconnection requires the same level of interconnection studies for a 25 MW wind plant as for a 1000 MW coal-steam plant, Further, as each study is completed, the dynamics of the network often change, rendering earlier studies invalid. This becomes an expensive, time consuming hurdle for most wind projects. What is needed in each region for cost-effective deployment of wind power is an integrated study such as the MISO/Wind-On-the-Wires/AWEA study of 10,000 MW of wind that was recently completed. The role of the wind program is to provide technical information and assistance where needed.

The program will continue its active participation in regional transmission planning processes. The SSG-WI/Clean Energy Plan for the West transmission planning and the New England Wind Barriers Project are examples. Support for the development of reliability methods that treat wind in a non-discriminatory fashion by NREL staff and consultants will continue, as will program engagement in regional reliability methods development.

Application and Implementation

Grid Rules Development – As a low capacity factor, variable resource, often located far from load, deployment of wind energy is impacted by the FERC-driven transmission organizational restructuring processes which are setting the stage for future grid treatment of wind. Under many existing penalty-based rules, proffered in FERC Order 888 to drive good market behavior, wind is inappropriately disadvantaged. FERC's proposed order, in 2003, on Standard Market Design would be a major improvement, but that order now looks unlikely to be adopted soon because of regional concerns about roles and responsibilities. If that proves to be case, wind energy stakeholders armed with information must be at the table in each regional for both interim and future rule development processes. This is a major challenge for the entire wind energy community. The methods developed in other tasks must be presented and applied to specific grid rule development processes in these venues.

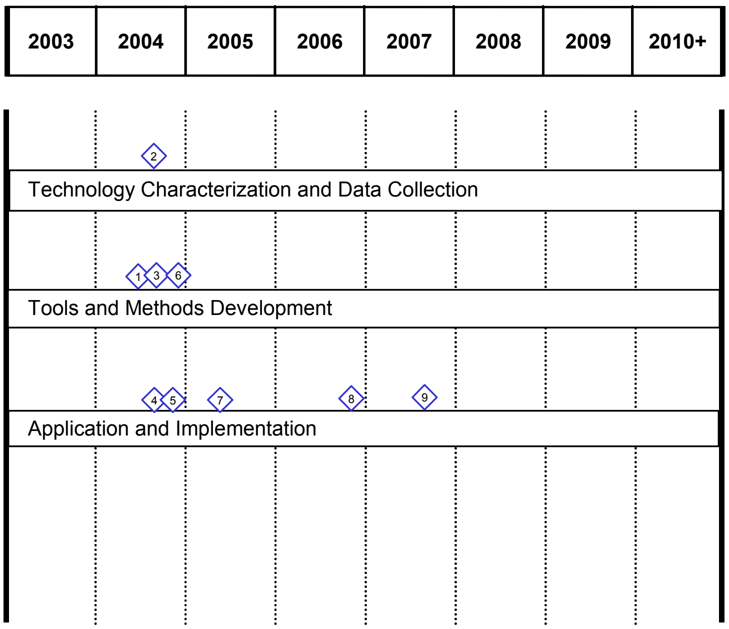
The program is actively engaged in supporting regional processes to develop grid rules for wind. Efforts in this area include: 1) Participation in Western Electric Coordinating Council (WECC) and RTO West processes; 2) Supporting the efforts of program consultants to quantify the costs and benefits of wind integration, including regulation impact and capacity credit, into the CAL ISO; 3) Monitoring New England ISO and New York ISO processes; and 4) Working with the Western Interstate Energy Board on "A Project to Facilitate the Sharing of Wind Energy Information Across the Western Interconnection."

Operational Impacts Mitigation Strategies – As wind deployment expands, costs for the integration of wind onto the grid may increase, especially at higher penetrations. Both short and longer term mitigation of intermittency issues, including wind plant forecasting and control, application of energy storage and regional cooperation, could reduce additional integration costs. In the near term, efforts in this area will include examination of wind and hydropower integration opportunities. Early efforts will perform site-specific analyses and case studies for WAPA and BPA. In the longer term, efforts may include wind integration with storage and wind generation of hydrogen.

5.1.5 Milestones

Milestones for the Systems Integration subkey activity provide planning guidance and a means by which progress can be tracked.

Systems Integration



Milestones

1. Facilitate development of transmission scenarios for two regions through NWCC planning forums
2. Complete one year of wind farm data collection for 3 RTOs or utilities
3. Complete dynamic models of wind farms and clusters for grid-level and distribution-level influences harmonics, machine dynamics, flicker, reactive power
4. Updated version of Hybrid2 software
5. Draft reports on hydro integration analyses for two river basins
6. Publish methods for treating wind in grid scheduling framework
7. Promote development of consensus utility transmission planning principles
8. Complete high penetration study, with validation, for one RTO
9. Complete mitigation study for RTO studied in 2006

5.2 Technology Acceptance

The Technology Acceptance subkey activity works to provide information about wind energy technology and its potential benefits to the stakeholder community, to allow informed decision making and to reduce undue barriers to wind's use. The success of Technology Acceptance efforts in removing barriers will be key to the long-term success of LWST and DWT technologies in the marketplace.

5.2.1 Goal

The goal of the Technology Acceptance subkey activity is that "By 2010, at least 100 MW will be installed in 30 states." In targeting that longer-term goal, the Technology Acceptance effort is also striving to ensure that, by 2005, at least 20 MW will be installed in 32 states.

5.2.2 Technical Approach

Strategy

The strategy of the Technology Acceptance effort is to build local momentum for wind's use across the United States. A state-focused strategy acknowledges the critical role that states have played in policy making and incentive adoption in wind development to-date. The primary mechanisms for pursuing this subkey activity are the Wind Powering America (WPA) program and the National Wind Coordinating Committee (NWCC).

WPA was established in 1999 to identify barriers to wind's use and options for overcoming them, primarily at the state level. A package of technical assistance and outreach activities is aimed at key user communities – farmers and ranchers, Native Americans, federal facility managers, rural electric cooperatives, and consumer-owned utilities. WPA works with these stakeholders and state and local officials to form state coalitions, or Wind Working Groups, in conjunction with DOE's regional offices, and to build the local presence required to accelerate wind's widespread adoption. WPA has adopted a number of operating principles, including: working at the market margins; leveraging and building institutional partnerships; developing innovative pilot applications; replicating successes; utilizing existing national, regional, and local expertise; and coordinating with established wind institutional resources.

The strategy of the NWCC, a U.S. consensus-based collaborative formed in 1994, is to establish dialogue among key stakeholders, and catalyze appropriate activities to support the development of environmentally, economically, and politically sustainable commercial markets for wind power. NWCC members include representatives from electric utilities and support organizations, state legislatures, state utility commissions, consumer advocacy offices, wind equipment suppliers and developers, green power marketers, environmental organizations, agriculture and economic development organizations, and state and federal agencies. The Program provides the largest share of financial support for the NWCC, but does not determine its research and outreach agenda.

Performance Measures

The Technology Acceptance subkey activity is working to establish sustained momentum in the spread of wind energy in the United States. The Program has identified three phases of wind acceptance and is measuring its success in that context. Technology Acceptance planning activities focus program efforts on areas in the “No Wind Momentum” phase, which is generally characterized as being before 20 MW are installed in a given state. The second phase is termed the “Growing Wind Momentum” phase, and is roughly the time between when program activities have begun in a state and when the 100 MW target has been met. This phase is characterized by relatively intense Technology Acceptance efforts. Finally, in the “Sustained Wind Momentum” phase, which typically occurs after a state has reached the 100 MW target level, Technology Acceptance activities can frequently wind down, and focus can be shifted to other states. However, as will be described later, there may be strategic considerations under which activities in a state might continue well past the 100 MW level.

Table 6 lists the annual target levels that will be used to measure Technology Acceptance progress.

Table 6. Technology Acceptance Goals and Annual Targets

Year	Number of States With More Than 20 MW Installed	Number of States With More Than 100 MW Installed
2002	13	8
2003	19	10
2004	25	12
2005	32 (goal)	16
2006	34	19
2007	36	22
2008	38	25
2009	39	27
2010	40	30 (goal)

The interim targets associated with achieving 20 MW in a state have been part of WPA since its inception. That target was selected because of the program’s experience in Colorado. In that state, an initial installation of 22 MW, to serve the local utility, proved to be the catalyst for familiarizing state, local, and utility officials with wind and its benefits. At the 20 MW size, it was large enough to gain state-wide attention and to be used as a model for future expansion of wind.

The Technology Acceptance management team has developed a prioritized list of states that will be the focus of efforts over the coming several years. These states have been selected based on factors including wind resource, status of the local economy, political and institutional receptiveness, energy supply situation, and demonstrated local interest. While these plans are subject to change, as the Technology Acceptance effort adapts its strategy to meet evolving circumstances, the likely targets are shown in Table 7.

Table 7. Targets for Technology Acceptance

	FY04	FY05	FY06	FY07	FY08	FY09	FY10
Total Number of States with >100 MW	12	16	19	22	25	27	30
Target States	CO PA	ND WV NY	UT IL MD	NE MT WI	SD TN	MI VA	MA NC

Other indicators of progress will also be tracked. Among these are the number of states that either have or have had initial wind workshops, Wind Working Groups, anemometer loan programs, validated state wind resource maps, legislative and policy briefings, and published small wind guides. These additional indicators are used since they have been shown to be important elements for success in the early years of the Technology Acceptance effort.

As the Technology Acceptance effort achieves its goals, and produce the desired sustaining momentum, the Wind Program anticipates that the focus will change. For example, the need for resource maps and anemometer loans will end as momentum builds. The program expects that Technology Acceptance efforts will transition to a more-regional focus. However, the program management may decide that additional efforts would yield large returns in some states that have passed the nominal 100 MW threshold. One example might be where a single, first installation was very large, but was located in a geographically remote part of the state. Additional efforts could well result in a spread of wind's use to other portions of the state, including regions with lower wind speeds that could use the LWST or DWT technologies as they become available.

As that regionalization occurs, the programmatic distinction between Systems Integration and Technology Acceptance will be reduced, and overlapping functions will be eliminated. The program also expects that it will increase its cooperative efforts with DOE Office of Electric Transmission & Distribution for both the Technology Acceptance and the Systems Integration subkey activities..

Figure 14 shows how success in meeting Technology Acceptance goals will be tracked, and how activities will be planned on a state-by-state basis. The figure also shows the role of the Technology Acceptance Advisory Board, which will provide overall strategic guidance to the effort, and will have an important role in deciding when adequate sustained momentum has been achieved in a state, such that financial resources should be directed toward other states. The membership of the Advisory Board is drawn from a range of sectors, and includes personnel from the DOE Regional Offices.

The top portion of the figure shows which states are in which wind momentum category (as of the end of 2003). The map also identifies which states have been part of Technology Acceptance activities to-date, and which await future activity. Figure 14 also shows that the program will track the other indicators of sustained wind momentum, which were listed earlier. The bottom portion of the figure illustrates how the Program tracks activities, provides a projection of when targets will be met, and identifies expected future activities. Detailed status and planning information is kept for each state (for illustrative purposes, only Arizona is shown). This information is used to support program performance reporting requirements and to identify future priority program activities. The program maintains a state activity tracking data base to provide detailed information about activities and to assist the Advisory Board in its planning function.

5.2.3 Technical Challenges

Numerous institutional and informational barriers have slowed, and continue to slow, the adoption of wind power. These barriers are distinct from technology cost and performance issues, yet, ultimately, could prove to be just as important. For example, some states have aggressively adopted policies and undertaken other barrier reduction actions to facilitate the deployment of wind energy. Other states have not yet explored wind resources or the potential for wind to stimulate economic activity. The challenge for Technology Acceptance is to develop, disseminate, and support an appropriate mix of technical information for, and general outreach to, a reasonable number of states where there are strong wind resources yet little public or private wind momentum exists. Another challenge is to bring the wind message to potential users of distributed wind technology. By reaching out to farmers, ranchers, Native Americans, and other state and local stakeholders, WPA can help build a state-level coalition. By building

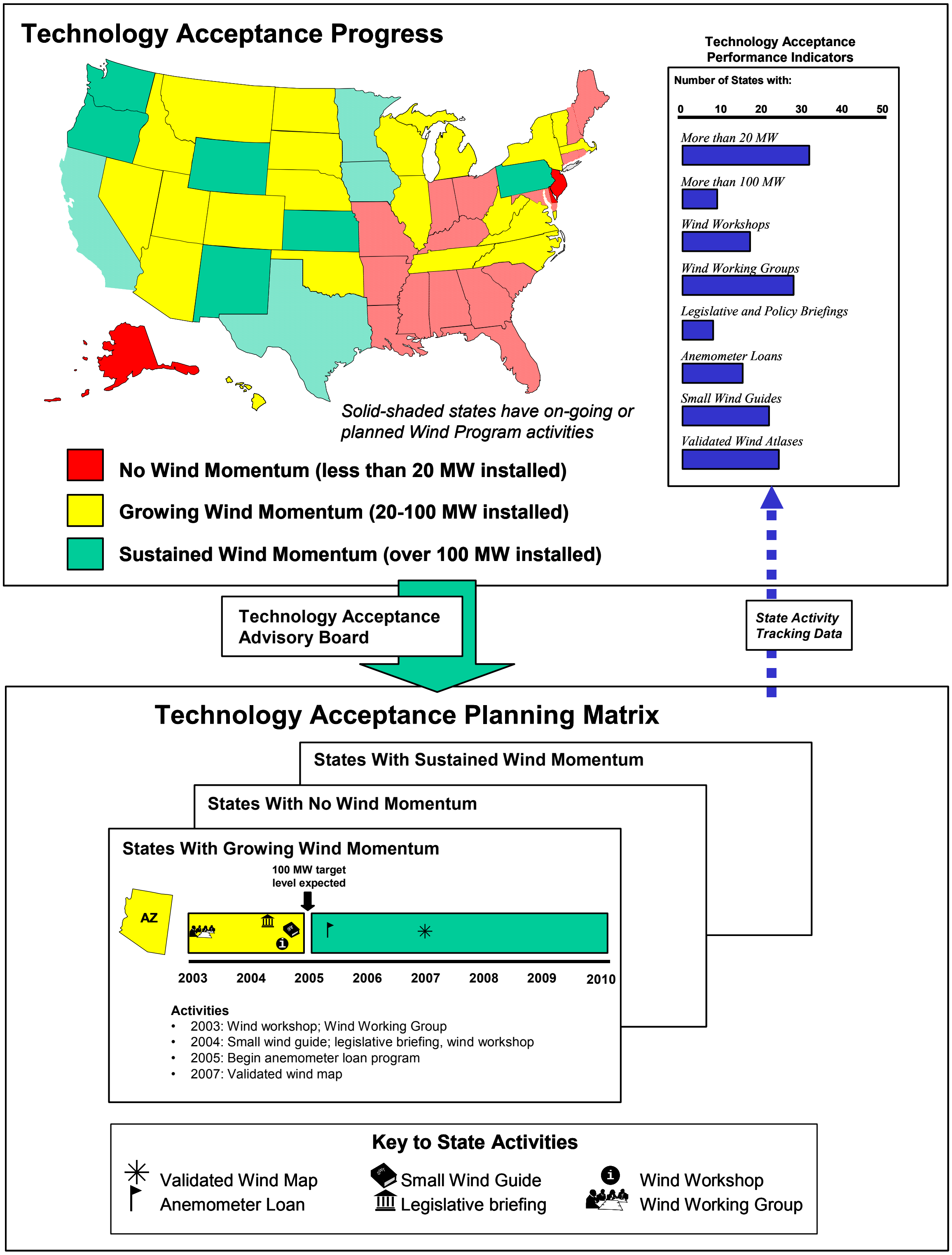


Figure 14. Status of Technology Acceptance Activities (end of FY2003) and Illustration of Planning Approach for Future State-Level Activities

bridges to environmental and regulatory communities, the NWCC help reduce barriers of interest at the national level.

5.2.4 Research Activities

The Wind Program's Technology Acceptance outreach and communications efforts complement the efforts being pursued under other elements of the Wind Program. This includes the Systems Integration subkey activity, as both are aimed at reducing undue barriers to wind's use. The Systems Integration work targets the more-technical barriers, while the Technology Acceptance momentum building efforts tend to address issues associated with state, local and consumer-owned utility unfamiliarity with the technology. The Program is pursuing five themes under the Technology Acceptance subkey activity.

Outreach to State-Based Organizations

The program has worked, over the past several years, to foster the formation of state wind coalitions to serve as focal points and local presence for outreach to local communities and stakeholders. As of the end of FY2003, formal state working groups had been established in 19 states across the U.S., from Virginia to Hawaii. Some of these working groups have become quite self-sufficient and Technology Acceptance support for them has been reduced. However, the majority of states still do not have functioning groups.

Through these state coalitions, a mix of WPA-supported technical and general activities is provided. For example, understanding the wind resource is the first step of many toward increasing wind capacity. WPA has found that many state, county and local stakeholders are unaware of their wind resources or are using information developed almost 20 years ago. To begin to address this information deficit, WPA launched an anemometer loan program with states to begin to increase familiarity with wind energy, in general, and to create the intellectual infrastructure necessary to move forward. Similarly, WPA began to cost-share development of updated state wind resource maps that show public and private officials, as well as landowners and other stakeholders, the extent of the wind resource in their state. There are currently 26 validated state wind resource maps. In FY2004, validated maps for Ohio, Indiana, Missouri, and Hawaii will be completed.

Wind provides substantial rural economic development opportunity because of the significant coincidence between wind resource and rural areas. WPA directly engages state-based agricultural organizations, as natural partners for rural wind development, to leverage their pre-existing contacts with the farming and ranching communities. Currently, wind farms in rural areas provide annual payments to the landowners, added state and local tax revenues, local revenues during construction, and some quality long-term jobs. The NWCC has directed recent efforts at developing techniques for estimating the local economic benefits of rural wind development, and has applied that work to three case studies. Over the next several years, the NWCC intends to work with local elected officials and economic development staff to educate them on how they can estimate wind's benefits to their local community. The NWCC has also played an important role in developing a better understanding of the transmission and distribution system infrastructure required to support rural wind development. This effort is coordinated with, yet complements, the Systems Integration activities to engage the regulatory community on wind issues.

WPA has established partnerships with national, state and local agriculture sector interests. A number of these, such as the American Corn Growers Association and the Cattlemen's Association, have joined to form the Agriculture-Wind Interest Group. WPA also works with the U.S. Department of Agriculture and others to take advantage of their extensive contacts with stakeholders in the rural community and to increase access to USDA's rural power systems funding programs. In 2003, the Wind Program, on behalf of DOE and EERE, began a cooperative effort to support USDA's implementation of the Farm Security and Rural Investment Act of 2002 ("the Farm Bill"), through a five-year program to support the greater use of renewables in rural communities.

WPA, in conjunction with the National Conference of State Legislatures, has provided legislative briefings on technical aspects of wind energy systems. The NWCC has an on-going wind farm siting work group that is detailing best practices for permitting wind generation facilities. An early NWCC focus on avian issues has played an important role in moving that debate toward having a factually and methodologically sound basis. Over the coming years, the Technology Acceptance effort expects to support the development of additional state wind working groups, as well as regional coalitions to remove barriers to the deployment of advanced wind turbine technology. Figure 14 emphasizes the important role of stated-based organizations in the program's Technology Acceptance effort.

Small Wind Outreach

The Technology Acceptance effort works to remove barriers to the increased use of distributed and/or small wind technology, in support of the program's Technology Viability efforts on DWT. The small wind outreach efforts provide important non-technology support to the industry's small wind roadmap, as described in the DWT chapter. Technology Acceptance activities include focused small wind energy workshops and meetings, development of a small wind calculator and modified wind resources maps, and development of state-specific Small Wind Guides containing resource, policy, technical information, and state contacts. As the technology development efforts under the Wind Program's DWT subkey activity lead to more cost-effective small wind turbines, the small wind outreach efforts will grow in importance.

Institution Building Through Utility Partnerships

The Technology Acceptance effort has established partnerships with public power organizations such as the American Public Power Association (APPA) and with rural cooperatives associated with the National Rural Electric Cooperative Association (NRECA). At the present time, the sharing of experience among the members of this community has helped build momentum for utility acceptance, and even support, for wind. For example, NRECA has sponsored workshops in Kansas, Colorado, and North Dakota to facilitate discussion, and Basin Electric Power Cooperative, with its pioneering support for 80 MW if wind in South Dakota and North Dakota, has become an important spokesman for the technology. The Technology Acceptance efforts coordinate closely with, and take advantage of, Utility Wind Interest Group activities under the Systems Integration subkey activity. In the longer-term, the outreach and communication partnerships with utilities will prove to be an important element of program support to regional groups fostering high penetration of wind.

Support for Native American Interest in Wind Power

There are no large-scale wind developments on Native American lands, despite the wide availability of excellent wind resources on those lands. A milestone was achieved, however, in early 2003 when the first Native American 750-kilowatt (kW) wind turbine was installed on the Rosebud Sioux Indian Reservation. Efforts are underway to educate Native American tribes with wind resources on how to develop them. WPA helped establish a Native American Wind Interest Group (NAWIG) which facilitates a Native American anemometer loan program and financial awards to tribes for wind exploration. WPA also provides a means for Native Americans to attend wind energy training programs under the WEATS (Wind Energy Applications and Training Symposium) program. A tribal wind resources program is helping Native American groups better understand the potential for wind use on tribal lands.

The program is currently working with some 20 tribes, to provide them with factual information on the use of wind. The program also works with other elements within EERE to increase wind's use on tribal lands, and supported the award, in August 2003, of $1.3 million to support the wind development efforts of three Native America tribes.

Wind Power Applications

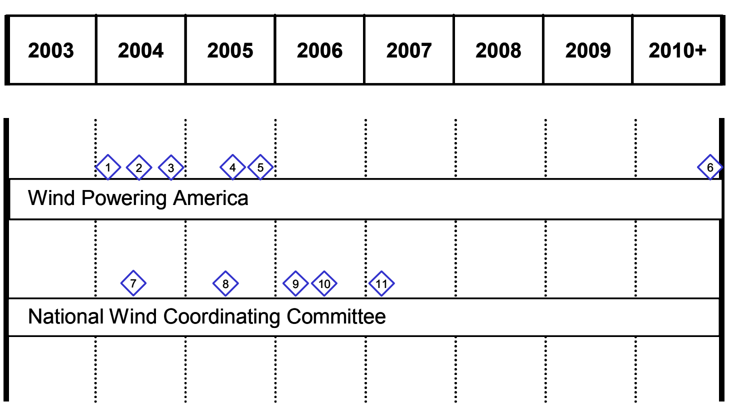
A portion of future Technology Acceptance efforts will be focused on communications and outreach required to help bring new applications for wind to the attention of key stakeholder groups. The applications focus is a result of growing awareness of the role that low-cost electricity and/or mechanical power can have in markets other than the bulk power market that has been the program's traditional target application. Potential new applications include the use of wind to provide clean water, through desalination, or to facilitate water management strategies for operators of hydropower facilities. Wind turbines may also be designed and tailored to serve in various agricultural, mining, or water pumping applications. WPA and the NWCC are both expected to be increasingly important as the deployment of wind turbines offshore advances, and as added communications and information dissemination requirements arise.

Since the federal government is the largest user of energy in the world, its use of wind power can play an important role in expanding early wind markets. Federal facilities are beginning to look to wind as a source of clean power. In general, however, the federal facilities are not the actual owners of the wind plants, but have agreed to purchase power from those plants. The Technology Acceptance activity will continue to work with the Federal Energy Management Program (FEMP) to foster use by federal agencies. An important success was achieved in 2003 when the Bureau of Land Management adopted procedures that include wind in BLM's long-term land plans and allow Programmatic Environmental Impact Statements (EIS) to streamline siting processes. These changes should greatly facilitate the use of wind on federal lands. The Technology Acceptance activity plans to work with th U.S. Forest Service to bring similar approaches to its planning processes.

5.2.5 Milestones

Milestones for the Technology Acceptance subkey activity provide planning guidance and a means by which progress can be tracked.

Technology Acceptance



Milestones

1. Regional aggregation efforts underway in 3 metropolitan areas
2. Launch economic development spreadsheet on WPA website
3. 30 validated state wind resource maps
4. 25 Wind Working Groups
5. 32 states with greater than 20 MW
6. 30 states with greater than 100 MW
7. Property values report
8. Workshop on economic development
9. Update of avian *Methods and Metrics* document
10. Initiate avian effects study of radio and digital interference
11. Transmission investment study

5.3 Supporting Engineering and Analysis

The Supporting Engineering and Analysis (SE&A) subkey activity provides a number of necessary functions to support industry and the program and to further wind energy technology deployment and application.

5.3.1 Goal

The efforts under this subkey activity are expected to help reach all four of the Wind Program's goals.

5.3.2 Technical Approach

Strategy

The strategy of the SE&A effort is to undertake, in consultation with industry, critical cross-cutting activities that span the needs of the wind stakeholder community, but are unlikely to be supported by individual companies.

Performance Measures

The success of this subkey activity, and progress in meeting its objectives will be reflected in the progress made toward the four wind program goals. The relative contributions and performance metrics can readily be quantified by the number of publications produced; the number of public/private collaborations initiated; and the number of new components and design modifications resulting from the program that are used and/or incorporated into LWST designs.

The achievement of the milestones provided below will also provide an indication of success. One indicator of success will be the acceptance of the U.S. certification process as being technically adequate in the domestic and international areas, such that U.S. wind systems are deemed to be safe, acceptable for interconnection with the electric grid, and of low performance risk, so that the financial community accepts them.

5.3.3 Technical Challenges

The stakeholder community's perception of the credibility of the Wind Program's efforts is important. The challenge is to establish processes, procedures, and analyses that enhance this credibility. Each of the activities under the SE&A activity presents its own set of unique challenges. For instance, European turbine manufacturers have long been required to be certified and that certification has served them well in the competitive arena. The unique challenge has been to close the gap between European and U.S. practice, and to define mechanisms for training and transferring the knowledge at the NWTC to an appropriate U.S. standards organization. The challenge for field verification efforts has been to bring carefully designed and operated data collection processes to a wide range of wind farm operations.

5.3.4 Research Activities

The Wind Program is pursuing three specific research activities under the Supporting Engineering and Analysis subkey activity:

Establishment of Certification Standards and Processes

Certification and design standards have historically focused on assuring that the design of a turbine is sound and safe and has been executed with good engineering practice. Standards need to be continuously updated to reflect the best knowledge on engineering practices and experience obtained over recent years. Having internationally recognized standards creates a level playing field in the market place and assures that every turbine meets a minimum level of safety. Over the past few years, NREL has set up a U.S. certification system, in partnership with Underwriters Laboratories (UL). International Electrotechnical Commission (IEC) standards are the basis for this certification program.

New standards, currently under development, will update or create new technical requirements and design techniques. NREL and SNL personnel will participate in IEC, IEEE and AWEA standards activities to provide technical support and ensure that standards provide adequate consumer and safety protection while avoiding creation of market and economic barriers. NREL will suggest guidelines on how to implement the standards for use by industry. Under the Certification Training project, NREL will continue to develop design evaluation, testing and quality system guidelines on how to implement the certification standards for use by industry and to provide specialized training to UL and industry partners to help them gain the necessary skills to sustain all of the services needed for a comprehensive certification program.

This task supports NREL's accreditation by A2LA to perform power performance, acoustic noise, power quality, structural loads, and blade testing. Accreditation supports efforts of our industry partners to develop new wind turbines because NREL testing then fulfills several important requirements for acceptance of test reports. To ensure continued accreditation by A2LA, staff will conduct activities specified in our Quality Assurance program including: a) completion of proficiency testing, b) conducting internal audits of power performance, acoustic, loads, and power quality tests; c) conducting a management review of the quality assurance system; d) and preparing for an A2LA, on-site assessment in the Autumn of 2004.

The Certification and Standards activity will begin a phase-down in 2005, with an orderly transition to Underwriters Laboratories (UL) over a few years.

Regional Field Verification

The Wind Program works closely with industry partners to research, develop, and verify advanced large and small wind turbine systems. These public/private partnerships include cost-shared research that leads to the development of prototype advanced wind turbines and field verification projects that prove the operational performance of early commercial wind turbines in different operating environments. The Field Verification task supports industry needs for gaining initial field operation experience with advanced technology wind turbines and verifying the performance, reliability, maintainability, and cost of new wind turbines in actual operating environments. It also helps expand opportunities for wind energy in new regions of the United States by tailoring projects to meet unique regional requirements. For over a decade, the Wind Program has supported field verification efforts through a number of separate related but distinct activities, including the Utility Wind Turbine Verification Program (TVP), Field Verification Program for Small Wind Turbines (FVP, Regional Field Verification Project – Phase I (RFV I), and Regional Field Verification Project – Phase II (RFV II).

In the short term, technical support will be provided for three verification projects, including 1) continued support for the RFV subcontract with Northwest Cooperative Development Center; 2) technical support to complete eight FVP quarterly reports; and, 3) technical support for the new RFV solicitation targeting Low Wind Speed Technology (LWST) turbines in commercial applications. The purpose of the Subcontract with NWCDC is to install up to 10 small wind turbines (max. size of 10 kW each) in the

Pacific Northwest, then evaluate the small wind turbine performance, operation, and maintenance experience in varied applications with regionally specific issues. The majority of these turbines will be installed during FY '04. Eight remaining FVP Quarterly Reports will be completed, and data collected from FVP wind turbines will be analyzed, compiled and summarized. These reports will be published and posted on NREL's web page.

Under this task, a proposal submitted in response to a targeted competitive Regional Field Verification (RFV) solicitation, issued in FY 2003, will be selected based on the Qualitative Merit Criteria for Best Value Selection. A Subcontract will be negotiated and executed with the winning Offeror. The winning proposal will support a verification project of advanced utility scale (100 kW or greater) wind turbines in characteristic low wind speed regions of the United States. The objectives of the RFV are to: 1) support industry needs for gaining initial field operation experience with advanced utility scale low wind speed technology turbines; 2) verify the performance, reliability, maintainability, and cost of new LWST turbines in commercial applications; 3) help expand opportunities for wind energy in new regions of the United States by evaluating unique regional requirements; and, 4) document and communicate the experience from these projects for the benefit of others in the wind power development community. NREL will provide technical, data collection, analysis, and reporting support to cost-sharing project hosts.

Supporting Technical Analyses and Communication Products

An important part of the Wind Program mission is the communication of research results and program activities to the different stakeholder audiences. This research activity supports and facilitates communication to promote the advancement of wind energy technologies. The Wind Program also directs cost- and performance-based technology assessments, and market assessments including tracking installed U.S. wind capacity and industry/utility plans for expansion. This effort informs the program of developments that could influence industry and program needs and priorities. The program also supports key collaborative efforts with the International Energy Agency (IEA).

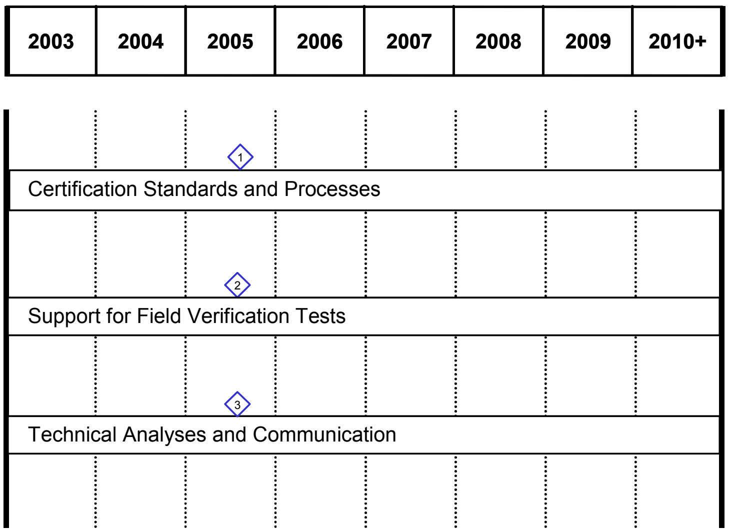
The program will publish and distribute communication products to appropriate audiences including government officials; researchers; members of the wind energy industry; utility engineers and planners; and others interested in the Wind Energy Program and the research conducted at the NWTC. NWTC and SNL personnel will lead the communication and analysis efforts by coordinating studies and the production and publication of technical papers, outreach brochures and materials, journal articles, web sites, and conference papers and exhibits.

The SE&A effort also supports the management of the program and the management and operation of the National Wind Technology Center (NWTC). The NREL/SNL program management team leads and manages over $34 million of complex and diverse Wind Program activities that are broken down into distinct tasks to assure appropriate high-level management focus for work that is performed at DOE's two principal National Laboratories for wind energy research. The NWTC facility is located on a 280-acre tract of land in northwestern Jefferson County, Colorado. From this location, NREL acts as DOE's lead research laboratory for the Wind Program, performing a range of management and support efforts critical to the overall success of the program. The NWTC management and operations task is comprised of five related but distinct projects: Site Management & Operations, NWTC Site Characterization, Certification Training, Program Management, and Site Field Maintenance.

5.3.5 Milestones

Milestones for the Systems Engineering and Analysis subkey activity provide planning guidance and a means by which progress can be tracked.

Supporting Engineering and Analysis



Milestones

1. Complete certification testing of two industry turbines at the NWTC
2. Complete first year reports on construction, operation, and maintenance performance for 3-5 Regional Field Verification projects
3. Complete update of programmatic technology characterization to support analysis efforts

Appendix A: Wind Research Portfolio Evaluation

At the core of the strategic planning framework is a Wind Technology Pathways Model. That model is shown in Figure A-1. *{It is important to note that all numerical values in this discussion are illustrative, and are provided simply as a way to guide development of the model's structure. Similarly, the list of technology improvement opportunities are also tentative and subject to change.}*

An important objective of the pathways model is to demonstrate that there are sufficient opportunities for wind technology to be improved, through program-sponsored R&D, such that the goals of the program can, in fact, be achieved. A second objective of the pathways model is to explore the implications on program success in meeting goals if a particular research project does not yield the expected technology improvement benefits. Although Figure A-1 may give the impression that the analysis framework is static and deterministic, the model treats the problem probabilistically to account for uncertainties in the outcomes of R&D.

Looking at the three portions of Figure A-1, starting at the top, in more detail:

Technology Improvement Opportunities

The program research staff has identified a set of technological improvements that are expected to contribute to the technology's becoming more cost effective. These have been termed the *Technology Improvement Opportunities (TIO).* Wind turbine design is a matter of constant tradeoff between the competing demands of lower cost, greater energy productivity, increased lifetime and durability, and maintenance cost. Achieving greater energy production may cost more, or it may cost less. Reducing materials to reduce capital investment may adversely affect O&M costs. These are the designers' tradeoffs, and they are captured in the model.

Total System Analysis

To illustrate how the model works in its simplest form, assume that there are only two TIOs. The first reduces capital cost by 10% and also increases energy production by 5%. The second, which is totally independent of the first, reduces cost by another 7%, but produces 4% less energy (a cost-effective trade-off). Simply adding the two together gives the outcome that cost is reduced by 17% and energy production is increased by 1%. Because cost of energy is proportional to capital cost and inversely proportional to energy production, the COE reduction from these two TIOs would be (1-0.17)/(1+0.01), or 17.8%.

As can be seen from Figure A-1, the outcomes of each TIO category (capital cost, energy production, and O&M) can be represented in the model by a range. Using a range of values is appropriate due to the inherent uncertainties about levels of success of R&D activities. In fact, the model actually represents this range as a probability distribution around a most likely value. The model generally uses a triangular distribution, such that the end points of the bars in Figure A-1 represent values with essentially no likelihood of occurring. The model can account for any potential interactions among the different TIOs. In contrast to the simple example just discussed, the model adds the potential changes probabilistically, and produces a range of potential outcomes for cost, energy production, and O&M. This probabilistic treatment is illustrated in Figure A-2.

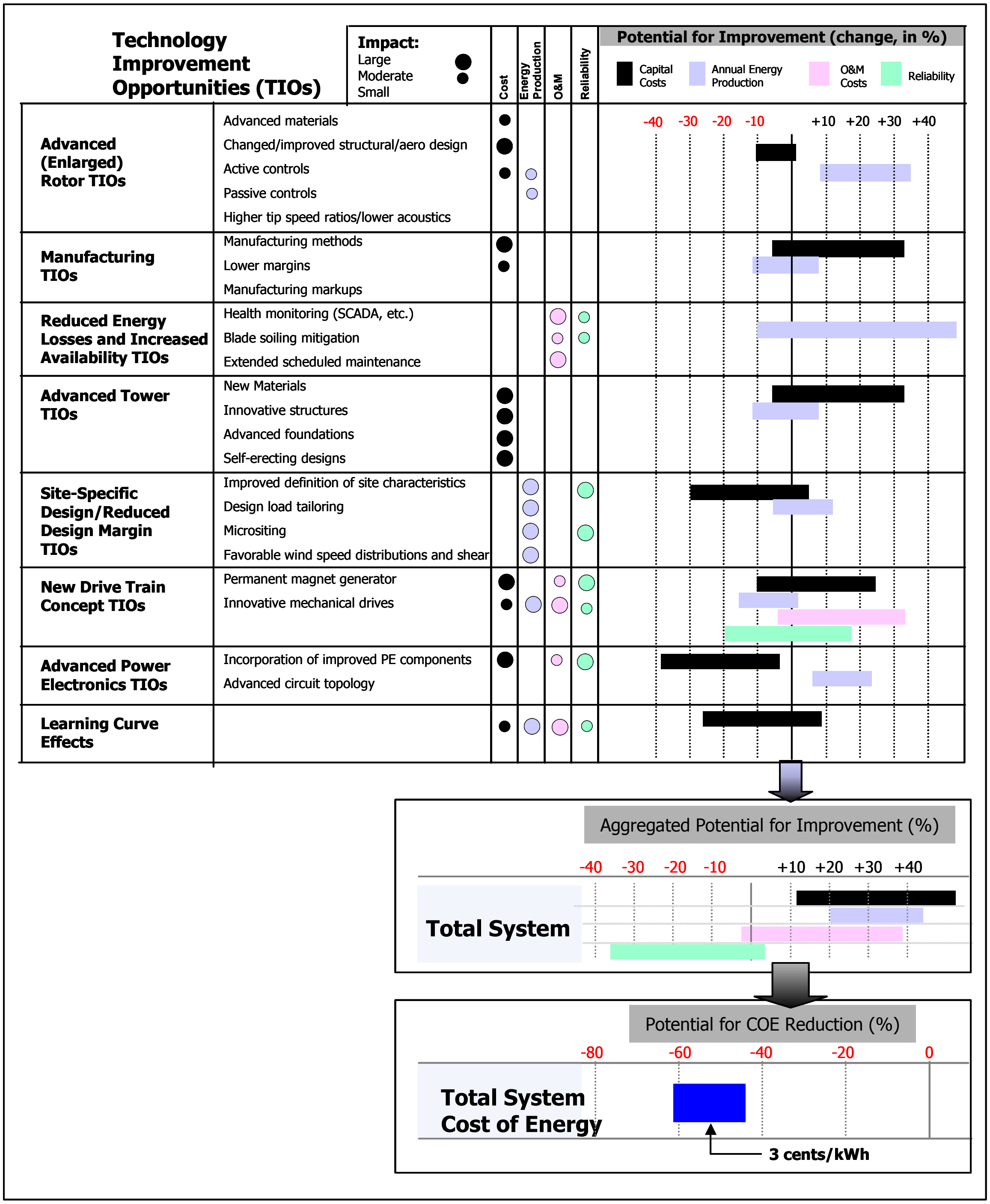


Figure A-1. Wind Technology Pathways Model

The model further accounts for the variety of technology configurations that might be used to achieve progress (e.g., through different gearbox designs). The model's ability to analyze the variety of approaches to meeting goals is what makes it a true "pathways" model. To illustrate, all turbines require a tower and rotor; but different tower designs could be married to different rotor designs, and still achieve the same level of cost-effectiveness. These combinations can be thought of as competing pathways. It is critical that the program be able to represent the fact that there are many potential approaches to meeting goals, that some are riskier than others, and that some might potentially yield a higher level of improvement in exchange for that additional technological risk.

Cost of Energy

The model uses a cash flow-based financial representation to calculate a levelized cost of energy (COE). The percentage changes in capital cost, energy production, and O&M are applied to the baseline COE to calculate the changes in COE due to program activities. In addition to the distribution of COE outcomes, the model also produces an estimate of the most likely value and provides a curve of COE versus probability of occurrence.

Assessment of Annual Progress

The Wind Technology Pathways Model also serves as the program's tool for quantifying annual progress in R&D. The program accomplishes that annual assessment through a process called the A*nnual Turbine Technology Update (ATTU)*. The progress measured by the ATTU is the combined result of research conducted under the LWST subkey activity and of those SR&T research activities that support the LWST public/private partnerships.

At the end of each fiscal year, program researchers provide summaries of progress made during the year. For SR&T, such progress will typically be measured in terms of research milestones achieved or significant technical advances realized. However, progress could also be measured by major milestones in the LWST and DWT activities, such as when new concepts, components, or prototypes are completed.

An advisory group to the ATTU process will collect all this input and develop estimates of progress made in cost, energy production, and O&M for each program research area. (This analysis will be performed for an aggregated set of research activities, i.e., at the task level, and will not attempt to ascribe a quantitative benefit to individual research subtasks. In focusing on an aggregated level of detail, the ATTU process operates at the appropriate level of reporting accountability for departmental and Presidential management initiatives.)

The data provided by the advisory group will be input into the Pathways Model to estimate annual progress, which will typically be described in terms of a decline in levelized COE.

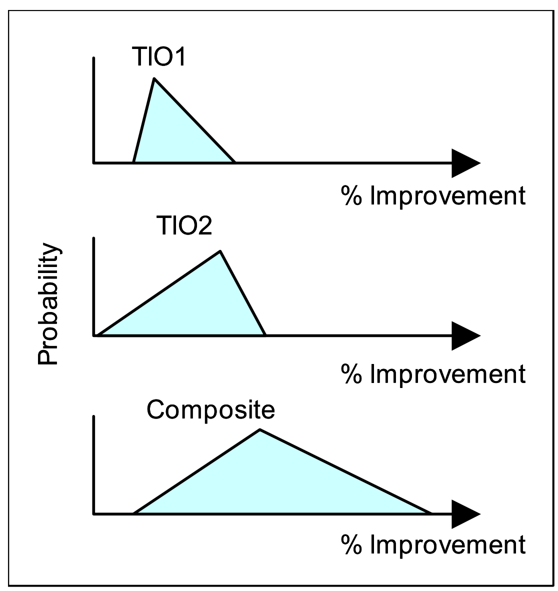


Figure A-2. Probabilistic Treatment of TIOs

Research Activity Prioritization

An important objective of the wind research evaluation process is to demonstrate that every research activity undertaken contributes in a meaningful way to the achievement of program goals. It is neither practicable, nor desirable, to try to quantify this linkage at the subtask level. It is, however, quite informative to make the linkage in a qualitative way, as a tool for forcing a constant questioning of the relevance of the subtask effort to overall program goals and objectives.

The program makes that qualitative linkage as shown in Figure A-3. As seen in the figure, every program subtask is assessed for its contribution to the various TIOs. As illustrated, some subtasks may be highly relevant to several TIOs, others to only one TIO, and yet others, when examined within this framework, may prove to have little relevance to any. As the program prioritizes and focuses its research portfolio, those subtasks that can apparently make only minimal contribution to technology improvement will be terminated. This process of annual re-examination of program subtasks also provides a means by which activities that have achieved most of their initial objective, i.e., have contributed to the TIOs to the extent possible, can be identified and terminated. The definition of these off-ramps is a critical element of the program's management strategy. In Figure A-3, subcontract 6 is an example of an effort that is no longer contributing to the program goals.

Impact: High H; Moderate M; Low

Technology Improvement Opportunities (TIOs)		LWST & DWT Subcontracts						SR&T Research Tasks			
		Subcontract 1	Subcontract 2	Subcontract 3	Subcontract 4	Subcontract 5	Subcontract 6	Research Activity 1	Research Activity 2	Research Activity 3	Research Activity 4
Advanced (Enlarged) Rotor	Advanced materials	M						H			
	Changed/improved structural/aero design	H						M	H	H	M
	Active controls	M	M					H	H		M
	Passive controls		M					H	H		M
	Higher tip speed ratios/lower acoustics		H					M	H	H	M
Manufacturing	Manufacturing methods	H									
	Lower margins	M									
	Manufacturing markups										
Reduced Energy Losses & Increased Availability	Health monitoring (SCADA, etc)										
	Blade soiling mitigation										
	Extended scheduled maintenance										
Advanced Tower TIOs	New Materials	H									
	Innovative structures	H							M	M	
	Advanced foundations	H							M	M	
	Self-erecting designs	H							M	M	
Site-Specific Design / Design Margin Reduction	Improved definition of site characteristics										
	Design load tailoring								H	H	
	Micrositing								H	H	
	Favorable wind speed distributions and shear								H	H	
Drive Train Concepts	Permanent magnet generator	H		M	H						
	Innovative mechanical drives	M	H	H	M						
Advanced Power Electronics TIOs	Incorporation of improved PE components	H		M	H	H					
	Advanced circuit topology					H					
Learning Curve Effects		M	H	H	M						

Figure A-3. Assessment of Program Activity Contribution to TIO Progress

Summary

In summary, the wind program has established a program research portfolio evaluation process that:

- Sets program COE goals based on a careful analysis of opportunities for technology improvement through program-sponsored R&D
- Tracks progress toward those goals using the same analysis tools as are used for setting goals, and reports that progress annually in terms of cost of energy
- Provides program funding guidance on activities that may no longer be contributing, or have the potential to contribute to, technology progress
- Ensures that all program-sponsored subtasks can be shown to contribute to achieving program targets for cost reduction, energy production enhancement, or O&M cost reduction.